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Volume II

Book 2
Appendix

Astronomy Sortie Missions Definition Study

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Itek

Bendix

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Astronomy Sortie Missions Definition Study
Final Report

VOLUME II
BOOK 2

ASTRONOMY SORTIE PROGRAM
TECHNICAL REPORT
APPENDIX

SEPTEMBER 1972

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PREFACE

This document is submitted in accordance with the Data Procurement Document Number 282, Data Requirement Number MA-04 under the George C. Marshall Space Flight Center Contract NAS8-28144. This is Book 2, an Appendix to Volume II of the Astronomy Sortie Missions (ASM) Definition Study Final Report. An updated and coordinated Baseline Experiment Definition Document (BEDD) for each of the candidate astronomy sortie mission telescopes and arrays is provided in the following sections of this book. The BEDD's were used to form the basis for the preliminary and final analyses, design and planning tasks in the Astronomy Sortie Missions Definition Study.

The telescope and array definitions provided are at least equivalent to the NASA Blue Book. In some areas such as operational, data, and control and display requirements, it was necessary to derive these low level requirements by: (1) similarity to existing or planned telescope and arrays; (2) use of previously developed inhouse parametric data; (3) extrapolation of existing data; and discussions with known authorities in the field of astronomy.

The optical, x-ray and high energy instruments which were selected as candidates for use on the Space Shuttle and which are defined in the following BEDD's include:

A. Solar Oriented Instruments

- 65 cm Photoheliograph (PHG)
- 25 cm Spectroheliograph (SHG)
- 32 cm X-Ray Telescope (XRT)

- Inner and Outer Coronagraph Assembly (COR)

B. Stellar Instruments - Telescopes

- 120 cm Stratoscope III (SIII)
- 100 cm Infrared Telescope (IRT)

C. Stellar Instruments - Arrays

- Wide Coverage X-Ray Detector
- Large Area X-Ray Detector
- Large Modulation Collimator
- Collimated Plane Crystal Spectrometer
- Narrow Band Spectrometer - Polarimeter
- Gamma-Ray Spectrometer
- Low Background Gamma-Ray Detector

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FOREWORD

The primary purpose of the Astronomy Sortie Mission Definition Study was to provide NASA with an overview of the Astronomy Sortie Mission requirements. The specific objectives of the study were to:

1. Evaluate the responsiveness of the sortie mission concept to stated scientific objectives.

2. Develop conceptual designs and interfaces for sortie missions including telescopes, mounts, controls, displays and support equipment.

3. Develop a system concept encompassing the Sortie Mission from mission planning through post-flight engineering and scientific documentation.

4. Provide development schedules and supporting research and technology requirements for Shuttle Sortie hardware.

The approach that was utilized in performing the study consisted of the following sequence:

1. Analyzing and conceptual designing the alternative candidate astronomy sortie mission program that maximized the utilization of common features.

2. Analyzing the astronomy sortie mission program to ensure compatibility between interfacing systems, evaluating overall performance and ensuring mission responsiveness, and developing a complete mission profile.

3. Analyzing the support subsystems to a depth which was sufficient to establish feasibility, compatibility with other subsystems, adequate performance, physical characteristics, interface definition, reliability level, and compatibility with manned operations.

4. Conceptually designing the selected astronomy sortie mission program which included defining the significant design features, dimensions and interfaces on layout drawings, and defining the telescope system physical characteristics and support requirements.

5. Providing development schedules and supporting research and technology requirements.

The final report of the study is contained in four volumes, of which this volume is Book 2 of Volume II. The four volumes of the report are:

Volume I - Astronomy Sortie Missions Definition Study Final Report: Executive Summary

This volume summarizes the significant achievements and activities of the study effort.

Volume II - Astronomy Sortie Missions Definition Study Final Report:

- Book 1 - Astronomy Sortie Program Technical Report

Book 1 of this volume includes the definition of telescope requirements, preliminary mission and systems definition, identification of alternative sortie programs, definition of alternative sortie programs, the evaluation of the alternative sortie programs and the selection of the recommended astronomy sortie mission program. This volume identifies the various concepts approached and documents the rationale for the concept and approaches selected for further consideration.

Volume II - Astronomy Sortie Missions Definition Study Final Report:

- Book 2 - Appendix

Book 2 of this volume contains the Baseline Experiment Definition Documents (BEDD's) that were prepared for each of the experiments considered during the study.

Volume III - Astronomy Sortie Missions Definition Study Final Report:

- Book 1 - Design Analyses and Trade Studies

Book 1 of this volume includes the results of the design analyses and trade studies conducted on candidate concepts during the

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selection of recommended configurations as well as the design analyses and trade studies conducted on the selected concept.

Volume III - Astronomy Sortie Missions Definition Study Final Report

- Book 2 - Appendix

Book 2 of this volume contains the backup or supporting data for the design analyses and trade studies that are summarized in Volume III, Book 1.

Volume IV - Astronomy Sortie Missions Definition Study Final Report: Program Development Requirements

This volume contains the planning data for subsequent phases and includes the gross project planning requirements; schedules, milestones and networks; and supporting research and technology.

CONTENTS

1.0 INTRODUCTION

Volume II, Books 1 and 2 summarize the work that was performed during the first three months of the study to arrive at a baseline astronomy sortie mission concept. The baseline concept defined was the basis for the more detailed analyses performed in subsequent work. As with all studies, the guidelines and groundrules at the start of the study are very often modified as the study progresses. This study was no exception, and many of the guidelines and groundrules that are identified in Volume II were either modified or deleted in subsequent work. A special section, Section 8.0 in Book 1, identifies the major changes in the astronomy sortie mission concept that was recommended as a result of the first three months of the study. In addition to the changes in the guidelines and groundrules, the information in Volume II is considered preliminary in nature. This volume includes coordinated and updated definitions of the telescopes and arrays for the astronomy sortie program concept that was approved as a baseline for the remainder of the study.

NASA, in its Blue Book,(1) has identified a group of optical, x-ray, and high energy instruments for use in space that would significantly advance the astronomical knowledge of the universe. Some of these instruments are candidates for use on the space Shuttle operated in the sortie mode (1-week missions with instruments remaining attached to the cargo bay). Shuttle sortie operations offer the possibility of a very productive astronomy program because the scientific instruments (spectrographs, radiometers, etc.) can be tailored to the objectives of each flight, and because scientific crewmen will be on board to evaluate and alter the

progress of the observations. Shuttle sortie operations will also reduce total costs by reducing hardware complexity (reliability goals of only 1 week instead of several years will be required) and by allowing common support functions (gimbals, C&D consoles, etc.) for all instruments.

The baseline experiments for the Astronomy Sortie Missions Definition Study were provided by the NASA/MSFC, COR. Solar oriented experiments for the study included:

1) 65 cm (modified to 100 cm aperture during the study) Photoheliograph (PHG);
2) 25 cm XUV Spectroheliograph (SHG);
3) 50 cm X-Ray Telescope (XRT);
4) 2.45 cm Inner Coronagraph (IC) and 4.0 cm Outer Coronagraph (OC).

The stellar experiments baselined included:

1) 120 cm Stratoscope III (SIII);
2) 100 cm Infrared Telescope (IRT);
3) High energy X-Ray and Gamma-Ray arrays.

The first task in the study was to review the experiment definition, contained in the available documentation, with special emphasis on those aspects that would particularly affect the Astronomy Sortie Missions Definition Study. Itek was responsible for defining the optical telescopes and Bendix was responsible for the X-Ray Telescope and the high energy x-ray and gamma-ray arrays.

In the performance of this task it was assumed that the reference document values of aperture, focal ratio, and field of view were accurate representation of the scientists' requirements. Other parameters, such

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as obscuration, pointing, and guiding, were examined and modified according to best engineering judgment. This judgment was based on past experience or first-order calculations for such factors as format, plate scale, obscuration, and wavefront error. Modulation transfer function (MTF) analysis was used to establish the allowable guide errors and the expected resolution.

The choice between film and electronic image tubes was not included in this study. For the analyses in this study it was assumed that a very high resolution film would be utilized. While this film may be too slow for many astronomical purposes, it comes closer to ultimate system resolution than any other sensor that might be considered. Exposure times also were not studied, but it was assumed that exposures would be long compared to the period of image motion.

Baseline performance and packaging parameters for the baseline experiments were taken from the documentation included in the references at the end of this section, but were modified where necessary.

The study also benefited from discussions with Dr. Mayfield at Aerospace Corporation on the various solar instruments, and with several NASA/Ames personnel about the IRT. It had been expected to work closely with NASA/MSFC on the development of the balloon version of the SIII, but the schedule did not allow any practical interchange of concepts or data.

A Baseline Experiment Definition Document (BEDD) was prepared for each of the telescopes and arrays. These BEDD's are contained in this volume and include the experiment objectives, requirements, interfaces, timelines and programmatic considerations.

2.0 BASELINE EXPERIMENTS DEFINITION DOCUMENTS

2.1 PHOTOHELIOGRAPH
(PHG) - 65 CM

ASTRONOMY SORTIE MISSION DEFINITION STUDY

BASELINE EXPERIMENT DEFINITION DOCUMENT (BEDD)

ASMDS 65 CM PHOTOHELIOGRAPH

PREPARED BY:

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CONTENTS

FIGURE

CONTENTS (Concluded)

1. INTRODUCTION

The purpose of this document is to define a 65 centimeter Photoheliograph which will be adopted for the Astronomy Sortie Missions Definition Study (ASMDS).

The scientific objectives, configuration, operational requirements, environmental requirements, data, pointing, and control and displays requirements, estimated ground support requirements, and post-mission refurbishment requirements are identified.

2. DISCUSSION

2.1 Scientific Objectives - The primary objective of the Photoheliograph experiment is high-resolution observation of the Sun. The resolution of the orbiting instrument allows detailed study of granulation in the Sun's surface (the photosphere). Solar flares will be studied in the H-alpha line and studies of spicules (thin, vertical jets of emitting gas) and spicule lifetimes will lead to a better understanding of this mode of convective energy transport through the upper chromosphere. Pictures are to be taken, in sequence, of any selected 3 arc minute field of view. The target will be the Sun, or areas no more than 6 arc minutes off its limb. Various wavelengths and various polarizations are to be selectable by the scientific observer. The Sun is an extended object, and the structure of the surface for tracking purposes is variable between different features and different wavelengths.

2.2 Instrument Description - The Photoheliograph is a 65-cm diameter diffraction limited telescope with image detectors and supporting electronics. Table I lists the performance characteristics for the telescope. Figure 1 shows the photoheliograph configuration consisting of two major subsystems identified as the telescope and instrumentation/support module.

The principal subsystems of the telescope module are listed below:

- Optics
- Structure
- Image Control
- Thermal Control

The principal subsystems of the instrumentation module are as follows:

- Structure
- Optics and Filters
- Cameras

The support module will house all the electronics for the instrument.

SPECTRAL COVERAGE	200 TO 700 NANOMETERS (2000 TO 7000Å)
F/NUMBER	F/3.85 PRIMARY; F/50 OVERALL
FIELD OF VIEW	8.7 X 10^{-4} RADIANS (3.0 ARC MINUTES)
FORMAT	28 MILLIMETERS (MM)
SCALE	31 X 10^{-6} RADIANS/MM (6.4 ARC-SECONDS/MM)
ANGULAR RESOLUTION	1.45 X 10^{-6} RADIANS (0.3 ARC-SECONDS)
SPECTRAL RESOLUTION	
BROADBAND CAMERA	10 TO 50 NANOMETERS (100 TO 500Å)
H-ALPHA CAMERA	25 PICOMETERS (0.25Å)
SPECTROGRAPH	2.0 PICOMETERS (0.02Å)

TABLE I PERFORMANCE CHARACTERISTICS FOR THE 65 CM PHOTOHELIOGRAPH

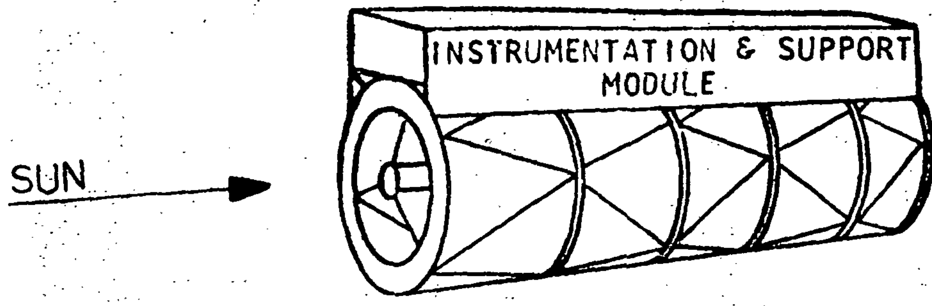

FIGURE 1 - PHOTOHELIOGRAPH CONCEPT

The diffraction limit of the telescope depends on the diameter of the optics as well as the quality. The requirement here is for a 65-cm diameter primary mirror, with quality and alignment of the telescope system such that the Rayleigh quarter-wave criterion is met by the system as a whole. The Photoheliograph is to make a permanent record of the scene, in picture format, at various wavelengths and provide data in spectrograph format from the spectral scanning instrument.

The MTF analysis of figure 2 for the Photoheliograph shows how the performance of perfect optics (Curve A) degrades with the introduction of 27 percent obscuration (Curve B) and with 0.05 wavelength wave front error (WFE) (Curve C). Two values for random image motion (smear or pointing stability error) are shown by curves D and E. The film curves used in the MTF analysis are degraded to represent 2:1 target contrast. The analysis is optimistic for very low contrast objects such as solar granular features, but pessimistic for high contrast objects such as sunspots.

The MTF analysis indicates little performance loss with a pointing stability error of 0.05 arc-seconds. Curve D crosses the 3404 film curve at 3.9 line-pairs per arc-second, corresponding to a resolution of 0.26 arc-seconds. Uncertainties in film choice and target contrast provides a "rounded-off" resolution of 0.3 arc-seconds. Since a spectrograph is included, the pointing accuracy should be set by the system resolution, 0.3 arc-seconds.

Functionally, the telescope module forms an image of a 3-arc minute section of the Sun, and relays the image to the instrumentation/support module. The instrumentation/support module uses beamsplitters and spectral filters to divide the image energy into five further images, which fall on five detectors - two film cameras, a spectrograph, a vidicon, and an image dissector tube. The film cameras and spectrograph record prime data; the vidicon provides a video display of the target; and the image dissector signal is used to focus the Photoheliograph and compensate for image motion. The support section houses the Photoheliograph electronics, including a programmer which relieves the observer of routine observing duties. The two major modules are integrated into a system configuration for attaching to the Shuttle pallet structure. Figure 3 shows the total Photoheliograph envelope.

2.3 Instrument Interfaces and Characteristics

2.3.1 Equipment Interface Diagram - The Photoheliograph interface diagram is shown in figure 4. This diagram identifies the major interfaces between the experiment subsystem modules and the support subsystems.

2.3.2 Scientific Equipment Characteristics - Experiment and support equipment characteristics are described below and summarized in Table II.

Telescope Module

The telescope module consists of the following:

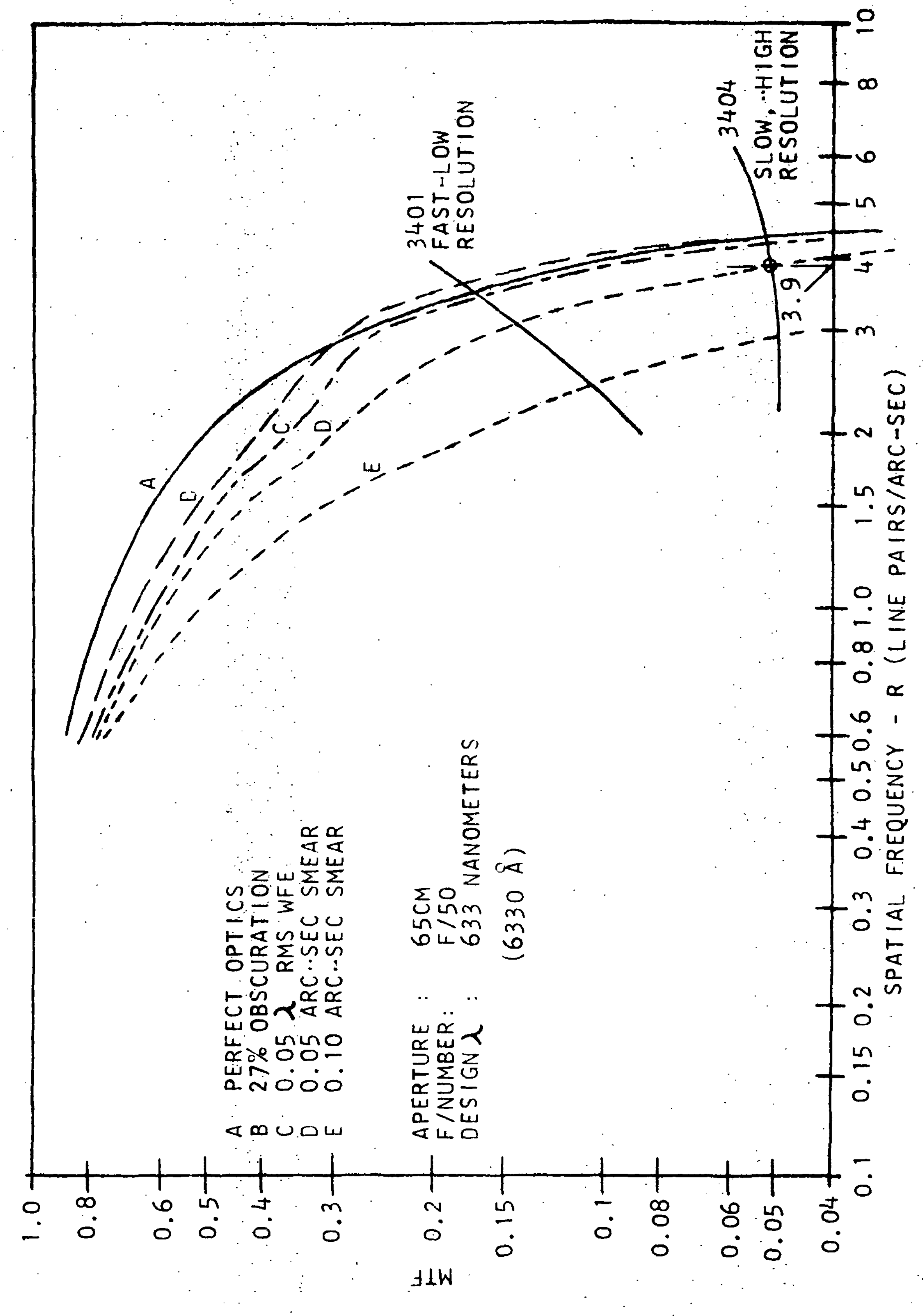

FIGURE 2 - MTF ANALYSIS OF 65 CM PHOTOHELIOGRAPH

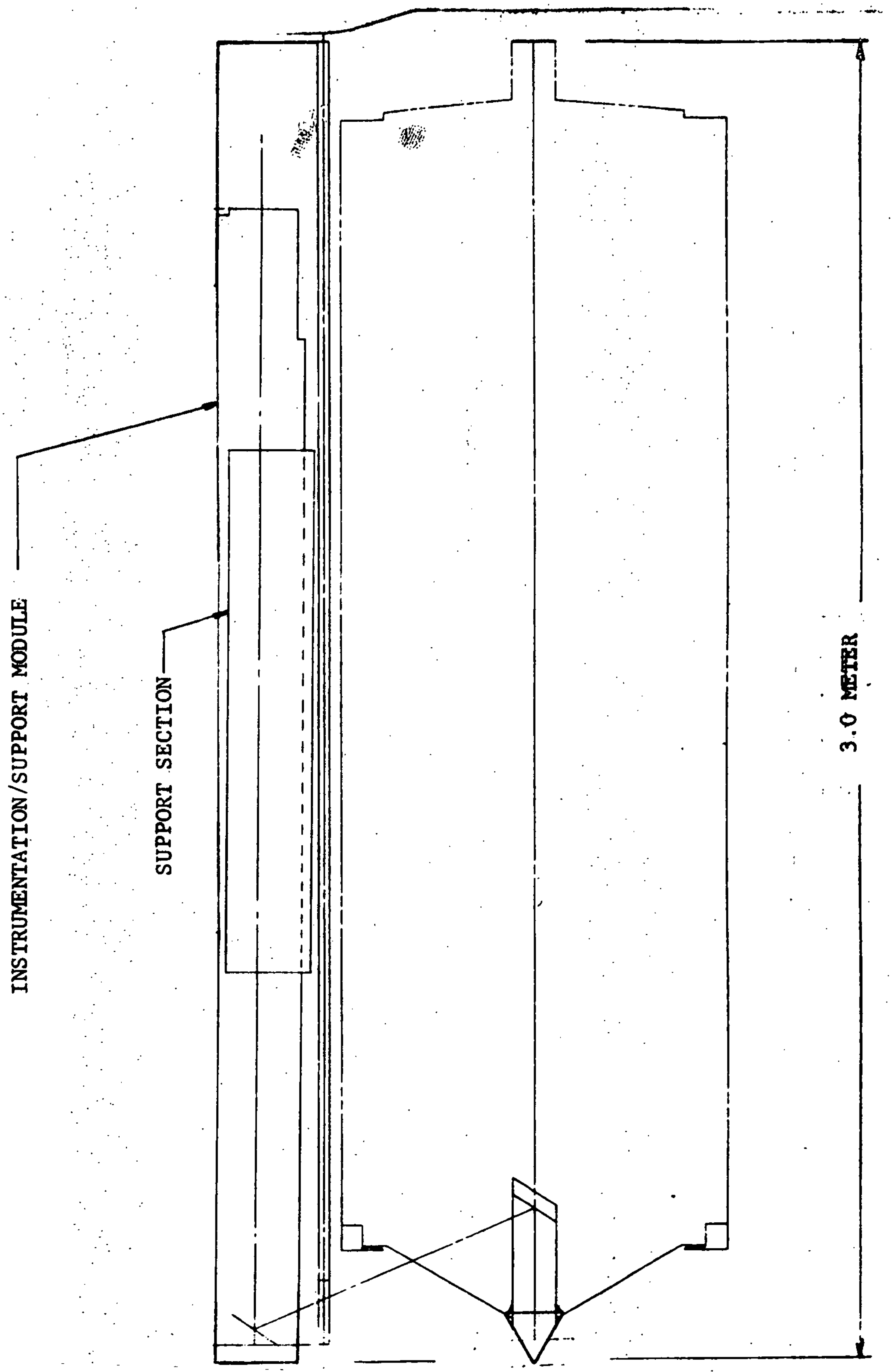

FIGURE 3a - PHOTOHELIOGRAPH ENVELOPE (SIDE VIEW)

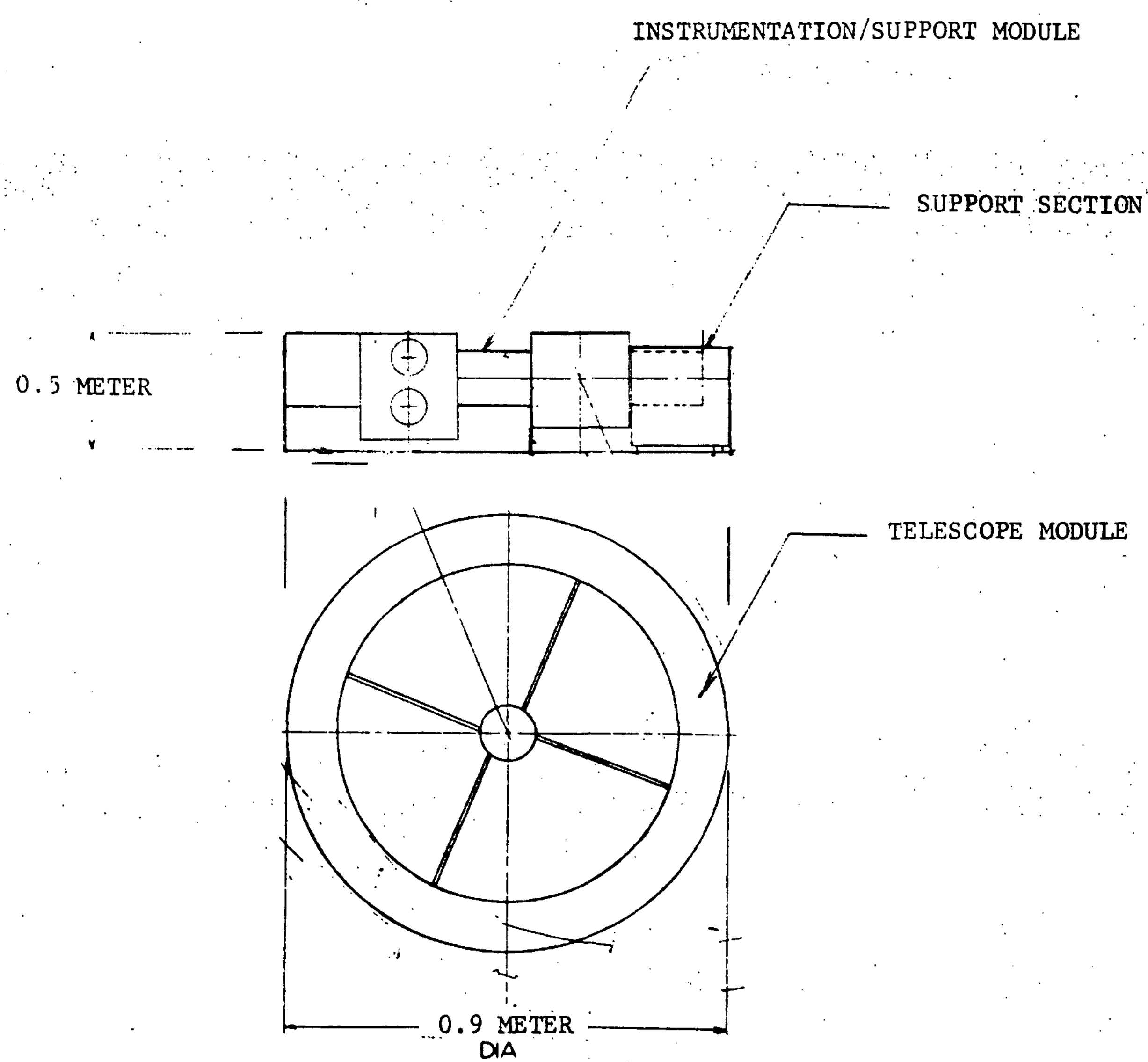

FIGURE 3b - PHOTOHELIOGRAPH ENVELOPE (END VIEW)

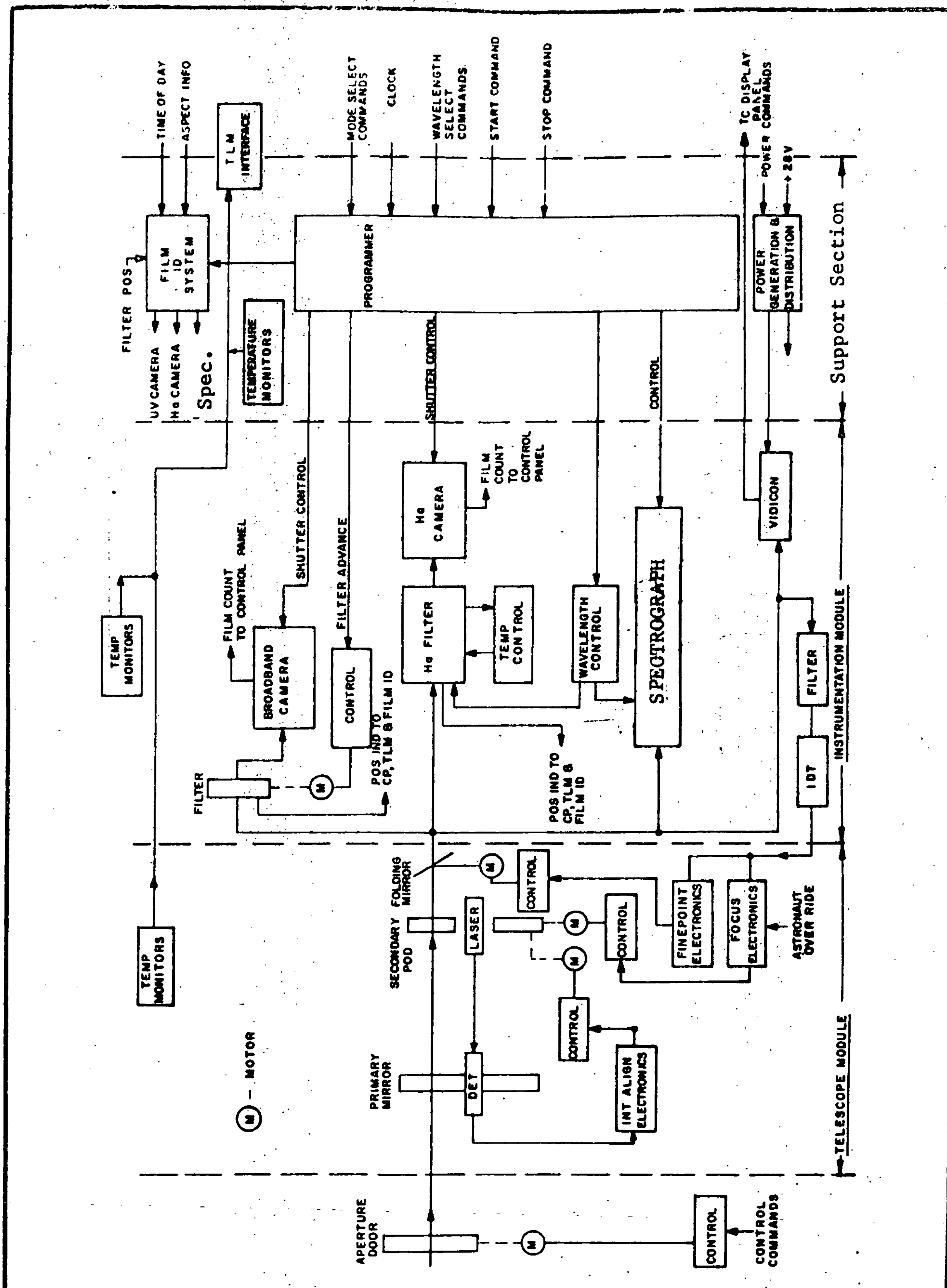

FIGURE 4 - PHOTOHELIOGRAPH INTERFACE DIAGRAM

DESCRIPTION	QTY	WIDTH, M (ft)	HEIGHT, M (ft)	LENGTH M (ft)	DIAMETER, M (ft)	VOLUME, M^3 (ft^3)	WEIGHT, Kg (lbs)	DATA, Kbps	POWER, WATTS
TELESCOPE MODULE		-	-	3.0 M (9.84 ft)	0.9 M (2.95 ft)	1.91 M^3 (67.5 ft^3)	530 Kg (1,168 lb)	-	-
Primary Mirror	1								
Secondary Pod	1								
Folding Mirror	1								
Focus/Align Electronics	3								
INSTRUMENTATION & SUPPORT MODULE	1	0.9 M (2.95 ft)	0.5 M (1.64 ft)	3.0 M (9.84 ft)	-	1.35 M^3 (47.6 ft^3)	-	3.6	16 Average
Second Folding Mirror Assembly									
Beamsplitters									
Filters									
Image Dissector Tube	-	-	-	-	-	-	270 Kg (595 lbs)		
Vidicon Detector								2.9 MHz	
Spectrograph								Film	
Hydrogen-Alpha Camera								Film	27 Peak @ Film Advance (2 Seconds)
Broadband Camera								Film	
Support Electronics	1	-	-	-	-	-	70 Kg (154 lbs)		
- Programmer									
- Film Identification System									
- Power Supplies									

TABLE II - SCIENTIFIC AND SUPPORT EQUIPMENT CHARACTERISTICS

- Optical subsystems, including primary, secondary and two folding mirrors, and their mounts
- Integrating structure
- Thermal control subsystem
- Image control subsystem, including alignment components and image motion compensation.

The telescope module is a cylindrical structure, 0.9 meters in diameter and 3 meters long, which mounts the telescope primary mirror and the secondary mirror pod. It produces a convergent f/50 light beam about 7.6-cm. in diameter which goes into one end of the instrumentation/support module. The basic optical design of the telescope module is a Gregorian type. The f/3.85 paraboloidal primary mirror forms a real image of the Sun about one inch in diameter at a heat-stop mirror. A hole in the middle of the heat-stop mirror acts as a system field stop, and has an effective diameter of about 2.54 mm. The heat-stop reflects the unused energy out through a side aperture of the telescope.

The primary mirror assembly consisting of the primary mirror, cell structure, and launch locks is secured to the main support ring at three places spaced 120 degrees apart.

Instrument/Support Module

The instrumentation/support module consists of the following:

- The Structure
- The Second Diagonal Mirror
- Optics and Filter
- Three Film Cameras
- Image Motion/Focus Detector
- Monitor Vidicon
- Support Electronics
- Spectrograph

The second diagonal mirror is mounted in the instrumentation/support module to provide a rigid platform between the second folding mirror, the image control detector, the data cameras, and the spectrograph.

The instrumentation/support module is mounted adjacent to the Photoheliograph. The light beam from the telescope module first hits a doubly-gimballed turning mirror which sends the beam to the cameras and spectrograph section of the instrumentation module. The gimballed mirror is controlled by servo signals which stabilize the image position against

small jitter inputs from the spacecraft. The mirror can also be positioned by the observer in order to center the image properly. The beam is broken up by optical beam-splitters into five images which impinge on the two data cameras, the spectrograph, a closed-circuit vidicon for the astronaut display, and an image dissector tube (IDT) whose output is used for image motion compensation and focus sensing. The two data cameras are identical physically, but use a different filter mechanism.

The spectrograph is a double Czerny-Turnes spectrograph. The H-alpha camera is preceded by a filter whose bandpass is 0.25 Å and whose adjustment range is ± 1Å, centered at 6563 Å. The H-alpha filter has an internal heater and temperature sensors to permit automatic temperature control to a few hundredths of a degree centigrade. The broadband camera is preceded by a filter wheel which carries several solid transmission filters, some for the visible spectrum, and one passing a few hundred angstroms at about 2000 Å. The vidicon is preceded by a solid interference filter which has a bandpass of less than 1 Å at the H-alpha line. The image dissector tube (IDT) is preceded by a 100 Å bandpass filter at 4100 Å. The IDT performs a repetitive cross scan 12 arc seconds in each dimension at a framing rate of 25 Hz. Data from successive scans are correlated in an image motion processor in the support module to yield image motion and focus information. The IDT is preceded by a movable element, either a lens or a mirror, which enables the focus at the IDT to be changed independently of the vidicon and data cameras.

The support section contains the system electronics for the Photoheliograph including a master programmer which permits simple selection, by astronaut command, of any one of several detailed observing programs. It also contains the image motion and focus processing circuitry and the power and distribution circuitry and acts as a central electronic tie point between the telescope and instrumentation/support modules and carrier support systems. The filter motors, the filter-wheel motor, and the temperature loops are controlled from the automatic programmer in the support module. The primary structure of the support section consists of a base plate and a case which is divided into compartments to ease fabrication and test of the different circuit assemblies. The circuits will be divided into the following electronic assemblies:

- Power Supplies
- Servo Motor Control
- Image Control
- Filter Control
- Television and Image Dissector Tube Control
- Data Handling

The overall size of the support section is approximately 20.3 by 20.3 by 114 centimeters.

2.3.3 Instrument Mounting and Alignment Requirements - The telescope housing is a cylindrical covered truss structure supporting the primary and secondary mirror assemblies. The structure consists of rings, connected by tubes arranged to form the truss structure. The cylindrical truss structure possesses good lateral stiffness and torsional strength. Tubular

truss members were chosen for good column strength and a high natural frequency. The material for the truss members is invar, or a similar low-expansion type nickel-iron alloy. The rings and fittings will be made out of aluminum. The low-expansion properties of invar produce minimum response to temperature changes occurring within the structure, the result being that the proper alignment and focus between the primary and secondary mirror is more easily maintained.

The instrumentation module structure will be an aluminum box containing the second folding mirror assembly, the beamsplitters, the filters and IDT and vidicon detectors. The three film cameras will attach to the outside of the box structure. The closed box structure will exclude stray light from the detectors, and provide the structural strength required. Aluminum will be used for its light weight and for ease of fabrication. The high thermal expansion of aluminum is not a problem in this part of the optical path. The high f/number of the telescope results in a depth of field greater than the thermal expansion or contraction over the anticipated temperature range. The closed box structure will also aid in maintaining a uniform temperature environment for the hydrogen alpha filter which requires close temperature control. The sides of the box will be bolted or welded together. The sides can have ribs and flanges where required and the remaining area can be kept to a minimum thickness.

The instrumentation module will be mounted at the side of the telescope. This position requires relay optics to channel the light flux to the cameras. The relay optics consist of the second diagonal mirror and a series of beam-splitters and mirrors. The beam-splitters and mirror mounting requirements are not critical.

The support module structure will consist of a main base plate fabricated from aluminum. The base will be physically divided by walls into compartments. The walls will provide support for the electronic assemblies. These walls will be welded to the base. Sectional covers in the form of "U" shapes will be used to protect the circuit assemblies. Removal of any one cover will allow access to the individual circuit assemblies.

The viewing aperture in the spacecraft must allow a half-angle field of view of 40 arc-minutes for the front aperture of telescope. A movable cover must be provided for the viewing aperture which can be closed during launch and non-operational periods in orbit. To prevent thermal distortion of the telescope due to uneven solar heating, the door should be opened only when the telescope axis is pointing within 23 arc minutes of the sunline. The door must be closed during spacecraft night to prevent excessive heat loss to space.

Actual alignment of the Photoheliograph (through the gimbals and pallet systems) must be lined up with the spacecraft reference axes within (TBD) radians. The true reference direction offsets between the instrument and the spacecraft axes must be known to (TBD) radians before launch.

2.4 Operations

2.4.1 Functional Flow Diagram - A gross outline of the functions required is shown in the Functional Flow Diagram of figure 5. Crew support will be required during solar observation with duties and time requirements dictated by the experiment operational mode being used.

2.4.2 Instrument Preparation Requirements - The Photoheliograph is deployed after stable orbit has been achieved. Deployment activities include:

- o Erection and deployment of the Photoheliograph from the space shuttle
- o Spacecraft coarse-attitude acquisition (prior to solar pointing acquisition)
- o Electrical power systems turn-on
- o Thermal control systems turn-on

General activation of the Photoheliograph includes:

- o Turn-on control and display panel, image control subsystem servos, camera and filter control electronics and thermal control electronics.
- o Turn-on and stabilization of telescope thermal control fluid systems and spectral filter thermal control.
- o Release of any launch locks required to protect the primary mirror and secondary mirror assembly.

Photoheliograph activation sequences for each orbit of solar observation include:

- o At spacecraft sunrise, the Sun will be acquired in the telescope field of view by pointing the Photoheliograph.
- o The aperture door will then be opened, allowing the primary mirror to be fully illuminated.
- o The focus and alignment servos will be enabled and monitored until focus and alignment drive rates stabilize within defined nominal ranges. This will occur as the telescope module nears thermal equilibrium.
- o Solar observation will be initiated with preprogrammed or manually controlled sequences corresponding to the desired mode of operation.
- o At spacecraft sunset the aperture door will be closed, and the servos and data cameras changed to a stand-by mode.

2.4.3 Instrument Operation Requirements - The Photoheliograph will be used to study both phenomena with short lifetimes and those whose lives extend over several spacecraft orbits. Phenomena that can be studied in one orbit or less include:

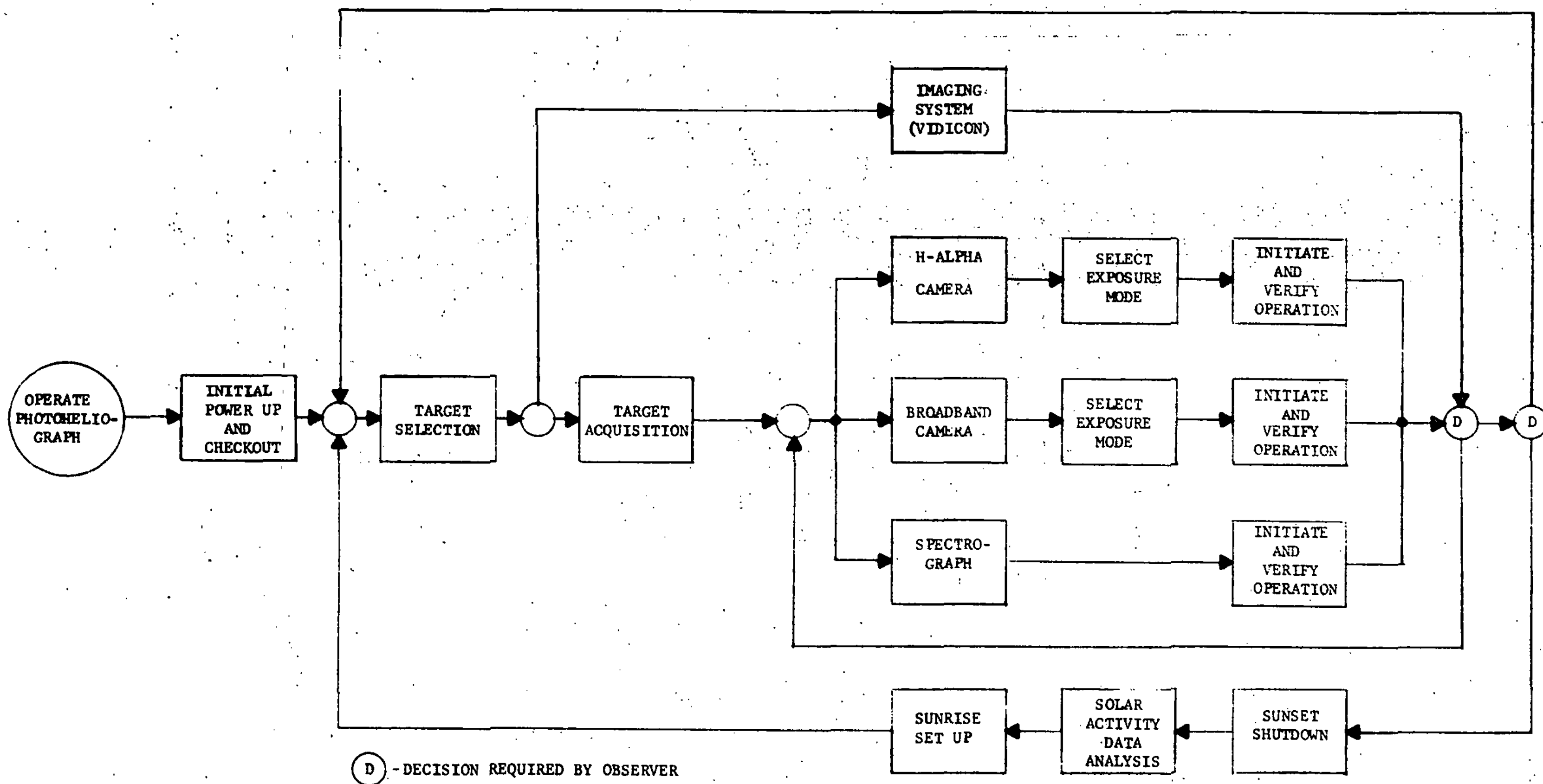

FIGURE 5 - FUNCTIONAL FLOW DIAGRAM - PHOTOHELIOGRAPH OPERATIONS

- Flares and active regions
- Fine structure and motions of photospheric granules
- Fine structure and motions of spicules and other chromospheric network features
- Chromospheric oscillations outside and within active regions
- Motions in prominences
- Detailed structure of filaments, bright rims, etc.
- Evershed effect in sunspots
- Ellerman bombs

Continuous observation is required for more than one orbit for the following:

- Changes in the chromospheric network
- Growth of active regions and emergence of magnetic flux
- Life histories of sunspots
- Patrol observations for flares and other rare, unpredictable events

The observing program required to achieve the scientific objectives is developed from the observing requirements listed above. The phenomena noted were classified into short-lived and long-lived features. An alternate method of classifying the features is whether they are observed on the "Quiet Sun" or the "Active Sun". These are relative terms, since the Sun is always active to some extent, and "Active Sun" is used here to describe a solar condition in which an active region appears that is unique, significant and changing rapidly enough to warrant fast data rates.

The Photoheliograph prime-time observing program is defined in terms of these two main types of observing: (1) "Quiet Sun" for preplanned measurements; and (2) "Active Sun" for targets of opportunity. Since active regions cannot be predicted before the mission, it is impossible to establish an exact timeline for an observing program for these two observing modes. Therefore, the timeline for each mode is independently established, and the total observing program can be assumed to be a combination of the various observing modes. (A third mode, "Time Sharing", has been used to allocate some data acquisition by the Photoheliograph from regions on the solar disk selected by some other experiment). Submodes can be designated within each main mode, which vary according to the camera system. These submodes group various spectral bands or lines, and permit the principal investigator to select numerous combinations of spectral characteristics and time responses. The submodes are defined in Table III.

The data sequence rates for the spectrograph, broadband camera, and H-alpha camera are simply one frame per spectral setting for each submode. All submode data sequences will continue to cycle according to the overall observing plan. The various cycle rates in Table IV are used as required to yield the desired scientific data. Combining these observing mode and rate data into a typical observing plan gives the total film frames indicated in Table IV. It can be expected that this film frame budget will be revised many times as the specific mission timelines are prepared. However, one possible combination of operations is depicted in figure 6. This sample profile was planned to allow accomplishment of the entire mission observing objectives in one 6-day mission.

BROADBAND CAMERA:	HYDROGEN - ALPHA CAMERA:	SPECTROGRAPH (DUAL RANGE):
Submode I:	Submode I:	Submode I:
UV Filter	Centerline (CL)	High Range
Submode II:	Submode II:	Submode II:
WL Filter - A	CL $+\Delta\lambda_1$	Low Range
WL Filter - B	CL $+\Delta\lambda_2$	
WL Filter - C	CL $-\Delta\lambda_1$	
	CL $-\Delta\lambda_2$	

TABLE III - PHOTOHELIOGRAPH INSTRUMENT OPERATIONAL SUBMODES

QUIET SUN MODE	ACTIVE SUN MODE
BROADBAND CAMERA (18000 FRAMES)	
Mode A (900 Frames) 3 days operation 1 orbit/day data recorded 1 frame/10 sec.	Mode A (6240 Frames) 6 days operation 11 minutes/orbit data recorded 15 orbits/day, 1 frame/10 seconds
Mode B (4500 Frames) 1 day operation 15 orbits/day data recorded 1 frame/10 sec.	Mode B - Flare Patrol (5760 Frames) 6 days operation 40 minutes/orbit data recorded 4 orbits/day, 1 frame/10 seconds
Mode C (600 Frames) 2 days operation 1 orbit/day data recorded 1 frame/10 sec.	
HYDROGEN - ALPHA CAMERA (24000 FRAMES)	
Mode A (900 Frames) 3 days operation 1 orbit/day data recorded 1 frame/10 sec.	Mode A - Active Region Mapping (10,800 Frames) 6 days operation 6 minutes/orbit data recorded 15 orbits/day, 1 frame/3 seconds
Mode B (4500 Frames) 1 day operation 15 orbits/day data recorded 1 frame/10 sec.	Mode B - Flare Patrol (7200 Frames) 6 days operation 40 minutes/orbit data recorded 5 orbits/day, 1 frame/10 seconds
Mode C (600 Frames) 2 days operation 1 orbit/day data recorded 1 frame/10 sec.	
SPECTROGRAPH CAMERA (3600 Frames)	
Mode A (400 Frames) 3 days operation 3 orbits/day data recorded 1 frame/minute	Mode A - Active Region Mapping (1080 Frames) 6 days operation 6 minutes/orbit data recorded 15 orbits/day, 1 frame/30 seconds
Mode B (680 Frames) 1 day operation 15 orbits/day data recorded 1 frame/minute	Mode B - Flare Patrol (720 Frames) 6 days operation 40 minutes/orbit data recorded 5 orbits/day, 1 frame/100 seconds
Mode C (720 Frames) 2 days operation 8 orbits/day data recorded 1 frame/minute	

Notes: Quiet Sun Mode;
Mode A requires three (3) consecutive days operation
Mode B requires one (1) day continuous operation
Mode C can be subdivided as desired

Active Sun Mode: Active Region Mapping and Flare Patrol submode observation times fill out the same orbit.

TABLE IV - TYPICAL PHOTOHELIOGRAPH OBSERVING PLAN

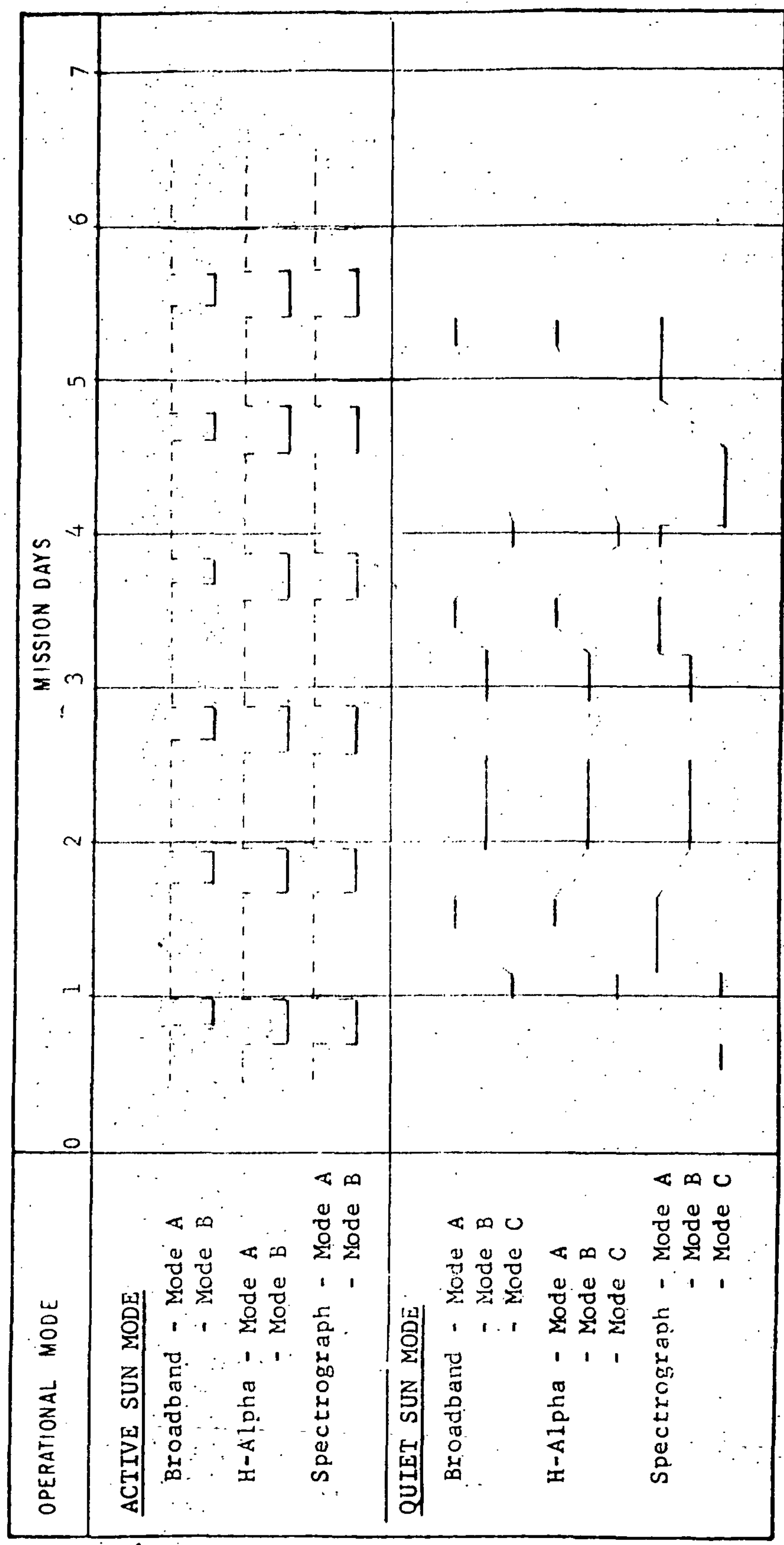

FIGURE 6 - Typical Time Line for 6-Day Observing Mission

2.4.4 Instrument Post-Operation Requirements - The major post-operation functions are:

a. Turn off instrument power
b. Place instrument in the caged gimbal orientation
c. Retract the instrument into the shuttle
d. Reset the launch constraints
e. Turn off support equipment power and prepare instrument for re-entry.

The operations are performed by the crew through the controls and displays console.

2.4.5 Typical Instrument Operation Timelines - The experiment operational characteristics described in the above paragraphs are summarized in Table V.

2.5 Environment - The environmental requirements and constraints associated with the Photoheliograph are listed in Table VI. The thermal interface characteristics are summarized and discussed below.

Thermal Interface

- Photoheliograph surface emissivity - 0.8 $\pm$ 0.1, black.
- Coolant to remove 50 watts from the telescope.

Power Absorption Within Instrument

- Solar power absorbed - 191 watts
- Electrical power - 16 watts

Distribution of Absorbed Power

- Direct radiation to space through viewing aperture - 155 watts.
- Absorbed by spacecraft thermal control system - 52 watts

Approximately 90% of the heat of the front surface of the primary mirror gained by solar absorption is conducted straight back through the mirror. At the back of the mirror most of the heat is lost by radiation. The plate and sleeve will be actively controlled to 283°K by cooling fluid from the spacecraft to properly absorb the radiated heat from the mirror. The cold plate also serves as a structural member, tying the six radial beams of the primary mirror cell structure together. A tubular thermal shroud, cooled by spacecraft cooling fluid, will be extended in front of the primary mirror. The shroud is secured to the telescope structure, will absorb radiated heat from the front of the mirror, and guard against transverse temperature gradients in the telescope truss.

2.6 Data - The main data link will consist of return of the exposed film. Normal housekeeping data will be transmitted. Voice communications will be required to allow

SUPPORT REQUIREMENTS \ EXPERIMENT OPERATING SEQUENCE		INITIAL													REPEATED												FINAL		
		SET UP					OPERATION								(4 / SEQ)				(3 / SEQ)				(1 / SEQ)						
							QUIET SUN				ACTIVE SUN				ACTIVE SUN				QUIET SUN				FLARE						
		INITIAL POWER-UP AND VISUAL CHECKOUT	RELEASE LAUNCH LOCKS AND ROTATE TELESCOPE	OPEN APERTURE DOOR	ENABLE ALIGN/FOCUS SERVO AND STABILIZE SYSTEM	SELECT TARGET	POINT TELESCOPE	ALIGN SECONDARY	ADJUST FOCUS	OBSERVE TARGET	POINT TELESCOPE	ALIGN SECONDARY	ADJUST FOCUS	OBSERVE TARGET	POINT TELESCOPE	ALIGN SECONDARY	ADJUST FOCUS	OBSERVE TARGET	POINT TELESCOPE	ALIGN SECONDARY	ADJUST FOCUS	OBSERVE TARGET	POINT TELESCOPE	ALIGN SECONDARY	ADJUST FOCUS	OBSERVE TARGET	CLOSE APERTURE DOOR	STOW AND LOCK TELESCOPE	TURN OFF TELESCOPE SUPPORT SUBSYSTEMS
	TIME (MINUTES)	50	34	2	10	3	3	6	12	18	3	3	3	30	3	1	3	30	3	1	3	18	3	1	3	60	2	67	6
CREW PARTICIPATION		X	X	X	X	X	X	X	X	(X)	X	X	X	(X)	X	X	X	(X)	X	X	X	(X)	X	X	X	X	X	X	X
EXPERIMENT EQUIP-MENT	PHOTOHELIOGRAPH	X	X	X	X		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X		X	X	
	HYDROGEN ALPHA CAMERA				X					X				X				X				X							
	BROADBAND CAMERA				X					X				X				X				X							
	SPECTROGRAPH CAMERA				X					X				X				X				X							
	IMAGE DISSECTOR				X			X	X	X		X	X	X		X	X	X		X	X	X		X	X	X			
	VIDICON				X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
	SUPPORT ELECTRONICS	X			X			X	X	X		X	X	X		X	X	X		X	X	X		X	X	X			
SUPPORT	(CONTROLS & DISPLAYS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	(GIMBALLED MOUNT)	X	X				X				X				X				X				X					X	
	POWER (WATTS) INSTRUMENT PROFILE	10	10	10	20	15	15AVE,35PK				15AVE,35PK				15AVE,35PK				15AVE,35PK				15AVE,35PK				10	10	-
	DATA PROFILE (BPS)	100	300	300	400	← 5100 BPS →																					400		-

TABLE V - TYPICAL INSTRUMENT OPERATIONAL CHARACTERISTICS

BEDD

	OPERATING	NON-OPERATING
MECHANICAL		
• Vibration	Vibration loads must not cause deflections within the telescope greater than TBD micro-radians.	With launch locks set, stands launch and re-entry loads.
• Acceleration	g-loads must not cause deflections within the telescope greater than TBD micro-radians.	
• Acoustics	N/A	
THERMAL	$291^{\circ}K$ to $297^{\circ}K$ ($283^{\circ}K$ Cooling fluid for primary shroud)	$263^{\circ}K$ to $297^{\circ}K$
ATMOSPHERIC		
• Humidity	Less than 40%	Less than 40%
• Pressure	10^{-7} Torr (1.33×10^{-5} N/m^2)	0 to 15 psi
• Contamination	Sensitive	(Telescope Covered)
EXTERNAL INTERFERENCES		
• Magnetic Fields	N/A	N/A
• RF Fields	Less than TBD watts-meter^2	N/A
• Ionizing Background	TBD	Total dose on film - less than 20 mJ/Kg

TABLE VI - ENVIRONMENTAL REQUIREMENTS AND CONSTRAINTS

the principal investigator to suggest desirable regions for study and to consult on experiment operations. The data handling subsystem will consist of the following components:

- o Telemetry Interface
- o System Programmer
- o Film Identification System

The telemetry interface will condition analog and digital housekeeping data signals for presentation to the spacecraft telemetry system. The system programmer will provide the necessary signals to the cameras, filters, etc., to automatically sequence the system in a pre-selected mode. The programmer will also generate and supply sequencing signals to the telemetry interface electronics. The programmer will also generate and supply sequencing signals to the telemetry interface electronics. The programmer will essentially be a small computer, which will be built using standard design techniques and components. It will be accessed from the C&D panel by selecting operation mode, wave-length-selected options, frame rates, etc. The film identifications system will present scientific correlation data to the camera diode matrix display. This data will be updated at every film exposure, allowing complete correlation of scientific data.

Digital Data - Four 10-bit words of digital sub-multiplex data will be generated for the following functions: mechanism position monitors, polarization analyzer position monitors, status indications, etc. Digital data will operate at 0 to 5 volt signal levels.

Analog Data - Seventeen analog sub-multiplexed channels will be generated. Data operating at 0 to 5 volt signal levels will be used for the following functions:

- o Voltage monitors
- o Current monitors
- o Position error monitors
- o Temperature monitors

Photographic Data - Ground telemetry is not required for prime data. All scientific data will be recorded by the three film cameras contained in the experiment. A light emitting diode array will be used to display scientific correlation data to each of the cameras. This data will include:

- o Time of day, and date
- o Spacecraft yaw
- o Spacecraft pitch
- o Spacecraft roll
- o H-alpha filter wavelength
- o Broadband filter wavelength
- o Polarizer state
- o Data redundancy

Film Camera - There is a common design data camera that mounts to the instrument in three different places. The cameras are physically similar. They are of rectangular configuration with the approximate dimensions of 20 inches long, 10 inches high and 5 inches wide. Each camera will hold TBD feet of 32-mm film. The cameras will not have lenses. The images will be formed by the instrument and spectrograph and the image plane will be coincident with the film plane. The cameras will record images in different wavelengths. This is accomplished through the use of instrument-mounted filters and the spectrograph placed ahead of the film's light path.

Mode of Actuation - With a camera loaded with film and mounted to instrument, a frame will be exposed by an external pulse. The support module programmer will control the shutter exposure time, number of frames to be exposed and diode matrix bit data. Frame rate is two frames per second maximum. The camera shutter has two blades actuated by two small torque motors. The blades close out of the picture frame. When a command pulse from the on-board camera controller is received, Blade 1 opens allowing light to strike the film. When Blade 1 is fully open, a timing circuit is actuated which controls the time when Blade 2 will be energized, which ends the exposure. Exposure times may be varied from 1/50 second to tens of seconds. At the completion of an exposure when Blade 2 closes, an internal circuit is made which automatically advances the film one frame. Picture area will be 25 mm wide by 25 mm high. The total frame area will be 25 mm wide by 28.5 mm high. The extra 3.5 mm will be used for recording the binary data from the diode matrix.

Camera Operating Procedure - During launch, the cameras will be mounted on the instrument, loaded with film. While mounted, the film temperature must be controlled between 20 to 90°F, by the telescope shroud environment. All cameras will be pressurized at 5 psia to prevent the film's emulsion from outgassing. The gas is oxygen having a relative humidity which is adequate for the storage and handling of film. Prior to launch all cameras will be loaded with unexposed film and threaded into the cameras. Each camera holds TBD feet of film mounted on daylight loading flanged reels. As the film supply of any camera is exhausted, a switch will deactivate the drive mechanism. At the same time a warning light on-board the spacecraft will advise the astronaut that the film supply is exhausted.

2.7 Pointing - The spacecraft support hardware shall be capable of providing solar pointing to any point within 6.4×10^{-3} radians (22 arc-minutes) of the center of the solar disk.

2.7.1 Accuracy - Spacecraft pointing accuracy required is 2.4×10^{-5} radians (5.0 arc-seconds). The telescope fine pointing system will provide internal pointing accuracy to 1.45×10^{-6} radians (0.3 arc-seconds).

2.7.2 Stability - Spacecraft pointing stability will be 1.21×10^{-5} radians (2.5 arc-seconds) to keep an object within the range of the image control system and must not drift faster than 4.85×10^{-6} radians (1 arc-second) per second. The telescope fine pointing system will provide the final pointing stability of 0.24×10^{-6} radians (0.05 arc-seconds).

2.8 Controls and Displays - The functional requirements for the controls and displays required to operate the instrument are listed in Table VII.

2.9 Preflight/Postflight Ground Support - Photoheliograph Ground Support Equipment requirements include ground checkout equipment, handling and transport equipment, and special test equipment. Many of the requirements for each of the modules are similar and will be treated here jointly.

Instrumentation Module - The instrumentation module GSE requirements are very similar to those for the telescope module. The ground checkout equipment and the ground handling equipment will be the same design as for the telescope, except for the vibration fixture which is unique to each module. The electronic simulator will provide the interfaces to and from the instrumentation module that are required for normal operation and for diagnostic work. Optical inputs to the instrumentation module will be provided by an image simulator.

The image simulator is an optical device required to stimulate the three film cameras, the video system, and the image control detector. The simulator must provide a suitable image for all the spectral wavelengths involved in orbital operations to evaluate the image control system. Since tests must be run in the vacuum chamber, as well as under ambient conditions, the image simulator will be a fairly complex piece of test equipment.

Support Module - The support module does not require any unique GSE that is not required for either the telescope or the instrumentation modules. The electronic simulator provides all input and output signals peculiar to the support module and for diagnostic purposes. Diagnostic routines will be built into the programmer. Since the support module is small it can be handled with normal laboratory techniques and will only be shipped with the instrumentation module. A unique vibration fixture will be used to mount the support module to the exciter.

2.9.1 Ground Support Equipment and Facilities - The Photoheliograph will require several major pieces of ground handling equipment. These include a pallet simulator to which the instrument can be attached, with a cooled shroud that simulates the shuttle shroud. This pallet simulator must be capable of thermal vacuum operation. Individual vibration fixtures are required to mount each module to the exciter. This fixture must simulate the pallet to Photoheliograph vibration characteristics, and includes the use of turn table techniques. A handling and lifting fixture is required to lift, maneuver and transport the telescope module between various set-ups. The fixture must be equipped with shock absorption means to buffer the telescope against hoisting jolts. The lifting device will also be provided with means to rotate the telescope module from a horizontal to a vertical position. A shipping container is required for storage and transportation of the telescope module. The container will be a steel canister, split for access, and mounting the instrument horizontally. Lifting rings and casters will be provided. Trip shock and temperature recorders will be included to evaluate the transportation environment. The canister will be pressurized with dry nitrogen while in use.

FUNCTION	CONTROL	DISPLAY
GENERAL		
Main Power	Toggle Switch	Switch Position
Aperture Door	Toggle Switch	Status Light
Launch Lock System	Toggle Switch	Switch Position
Thermal Control	Toggle Switch	Switch Position
Automatic Focus	Toggle Switch	Switch Position
Manual Focus	Toggle Switch	-
Focus Status	-	Vertical Meter
Alignment Translate	Toggle Switch, (4 Position)	-
Alignment Rotate	Toggle Switch, (4 Position)	-
Alignment Status	-	Cross Pointer
Image Motion Compensation Override	Toggle Switch	Switch Position
H-Alpha Monitor HV	Toggle Switch	Switch Position
H-Alpha Monitor, Wavelength-Select	Rotary Switch	Switch Position
Set Mode Status	Toggle Switch	Status Light
H-Alpha Display	-	TV Monitor
H-ALPHA CAMERA		
H-Alpha Filter Heater	Toggle Switch	Status Light
H-Alpha Mode Select	Rotary Switch	Switch Position
H-Alpha Data Status	Toggle Switch	Status Light
H-Alpha Camera Power	Toggle Switch	Switch Position
H-Alpha Frames Remaining	-	5-Digit Counter
H-Alpha Frame Rate	Toggle Switch	Switch Position
BROAD-BAND CAMERA (BBC)		
BBC Power	Toggle Switch	Switch Position
BBC Mode Select	Rotary Switch	Switch Position
BBC Mode Status	Toggle Switch	Status Light
BBC Frames Remaining	-	5-Digit Counter
BBC Frame Rate	Toggle Switch	Switch Position
DUAL RANGE SPECTROGRAPH (DRS)		
DRS Power	Toggle Switch	Switch Position
DRS Mode Select	Rotary Switch	Switch Position
DRS Data Status	Toggle Switch	Status Light
DRS Frames Remaining	-	5-Digit Counter
DRS Slit Camera HV	Toggle Switch	Switch Position
DRS Slit Camera Monitor	-	TV Monitor
DRS Grating Select	Toggle Switch	Switch Position

TABLE VII - FUNCTIONAL REQUIREMENTS FOR PHOTOHELIOGRAPH CONTROLS & DISPLAYS

The major special test facility required for the Photoheliograph program is a vertical vacuum test chamber that can accommodate the complete Photoheliograph. A variety of optical and thermal tests will be performed on the telescope module alone and with the instrumentation and support modules. During such tests the Photoheliograph is supported vertically with the primary mirror at the lower end to reduce gravitational distortion effects. A specially coated optical flat is supported above the telescope; the laser interferometer is supported next to the telescope. The entire setup must be supported inside the chamber on special shock mounts to reduce seismic vibration inputs. Telescope, flat and interferometer are all supported by a fixture which includes the pallet simulator. The specially coated optical flat will transmit solar radiation except for reflecting a narrow spectral band that agrees with the wavelength of the laser interferometer. During tests with the interferometer the coating provides the reflective capability needed to make the interferometer system work, while allowing most solar thermal energy to pass through the mirror with little loss. Optical quality requirements of the flat are severe, particularly when its size and weight are considered. A laser interferometer is used to evaluate detail optical elements during lower level tests and to investigate the optical quality of the entire system during later tests. During tests of the telescope on the vertical fixture, the interferometer must be mounted inside the vacuum chamber. Since the device is not vacuum compatible a special sealed container will be required. Remote control capability for the interferometer adjustment system may be needed also.

During the vertical optical system tests previously discussed, means must be provided for bringing real or simulated solar energy into the vertically mounted telescope. Probably "real" energy will be easier to provide for an instrument of this size. To accomplish this a rather large heliostat will be required to track and reflect the Sun into the vertical setup. A special window will also be required in the vacuum chamber. Fortunately, high quality optics will not be necessary in the heliostat or window, since perfect imaging is not required. Actual imaging capability is checked with the separate interferometer system previously mentioned.

2.9.2 Test, Checkout and Calibration - Throughout the system assembly, calibration, qualification and acceptance testing, the modules will be operated independent of each other. Therefore, an electronic simulator is required to perform these efforts. This simulator will have four major sections that look electronically like the Photoheliograph modules. If program requirements dictate, each of these four sections can be designed to interface with adjacent sections similar to the flight hardware. This will enable reliable control over any module. In addition to performing the control function the simulator will provide all of the Photoheliograph monitoring and display functions planned for the Control and Display panel. Additional data monitors will also be incorporated for diagnostic checkout during system tests. The simulator can be designed to interface with the NASA Automatic Checkout Equipment to facilitate Photoheliograph integration to the Shuttle pallet.

Prior to launch, the telescope and instrumentation modules must each be aligned to the reference sensor within 10 arc seconds about the pitch and yaw axes and within 30 arc minutes about the roll axis. This alignment can be

accomplished by means of reference mirrors on the instrument and adjustable-length mounts. After launch, the alignment of the instrumentation and telescope modules with respect to the reference sensor shall be within 45 arc seconds about the pitch and yaw axes, and within one degree about the roll axis.

2.10 Post-Mission Refurbishment - The Photoheliograph will require refurbishment of the film cameras, calibration of the filters and spectrograph, and the normal alignment sequences before flight.

2.11 Orbital Parameters - Continuous sun viewing for six days is desired for the Photoheliograph. The minimum altitude must provide continuous sun viewing above an Earth atmosphere of 100 nautical miles at any inclination.

3. PROGRAMMATICS

3.1 Equipment Cost and Schedule - Schedule and cost estimates for the 65 Centimeter Photoheliograph are given in Table VIII.

3.2 Safety Considerations - There are no pyrotechnic or explosive devices required for the Photoheliograph. The film magazines will be capable of containing sufficient film for the seven day sortie mission to preclude extravehicular activity.

3.3 Reliability - Equipment reliability will depend on the level of effort devoted to reliability during design development, fabrication and test phases of the equipment. Less emphasis on state-of-the-art parts that require high reliability certification will result in reduced parts evaluation effort. Failure mode analysis will be limited to identifying single-point failures. In-depth analysis of end-item failures will be applied only to major problems. Receiving and in-process inspections will be limited to identified critical components. Material review board actions will not be started until the refurbishment phase. Change control will be at the End Item Specification level until the refurbishment phase, and then at the released engineering level.

4. NOTES

4.1 Bibliography - This BEDD contains information from the following

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)		(0.36)	(1.30)	(1.30)	(0.38)			$ 3.34
PRODUCTION-FIRST ARTICLE			(0.31)	(0.97)	(1.30)	(0.39)		2.97
								$ 6.31

TABLE VIII - SCHEDULE AND COST ESTIMATES, 65 CM PHOTOHELIOGRAPH

documents. No reference to the documents is made in the text.

a. <u>CIT Photoheliograph Definition Study</u>, NAS8-30190, Ball Brothers Research Corporation, Boulder, Colorado, April, 1971.

b. <u>CIT PHG, Sortie versus ATM Comparison Study</u>, NAS8-26799, Ball Brothers Research Corporation, Boulder, Colorado, November, 1971.

2.2 XUV SPECTROHELIOGRAPH (SHG)

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

BASELINE EXPERIMENT DEFINITION DOCUMENT (BEDD)

ASMDS XUV SPECTROHELIOGRAPH

PREPARED BY:

APPROVED BY:

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MARTIN MARIETTA CORPORATION
Denver Division
Denver, Colorado

CONTENTS

FIGURE

TABLE

CONTENTS (Concluded)

Page

TABLE (Cont.)

1. INTRODUCTION

The purpose of this document is to define a baseline XUV Spectroheliograph Telescope for the Astronomy Sortie Mission Definition Study.

The scientific objectives, configurations, operational requirements, environmental requirements, data pointing, and controls and display requirements, estimated ground support equipment and post mission refurbishment requirements are identified.

2. DISCUSSION

2.1 Scientific Objectives - The XUV Spectroheliograph records the image of the solar disk in several brightline (extreme UV) wavelengths simultaneously between 17 and 65 nanometers (170 and 650 Å).

2.2 Instrument Description - A band selection grating (spectrum selector assembly) and a multispectral film camera assembly are used to obtain images at selected XUV spectral lines. The concave grating includes figure corrections to improve the image quality. The grating is plated with gold and ruled at 3,333 lines/mm. An aperture of about 0.25 m with focal length of 3 m provides the scale factor and image brightness required. An unbacked thin film of aluminum possesses the desired wavelength transmission range, while reflecting the much more intense visible energy. As a further protection, thermal mirrors are placed at strategic points to reflect the zero order image and the first order visible range energy back out into space through the entrance aperture. The camera consists of a magazine to store the film, advance it to exposure position, and return the exposed film to storage. A shutter, operated on command, controls the exposure time. An aspect sensor is boresighted to the spectroheliograph telescope, to provide the crew with guiding information. An outline of the XUV Spectroheliograph is shown in figure 1. Table I lists

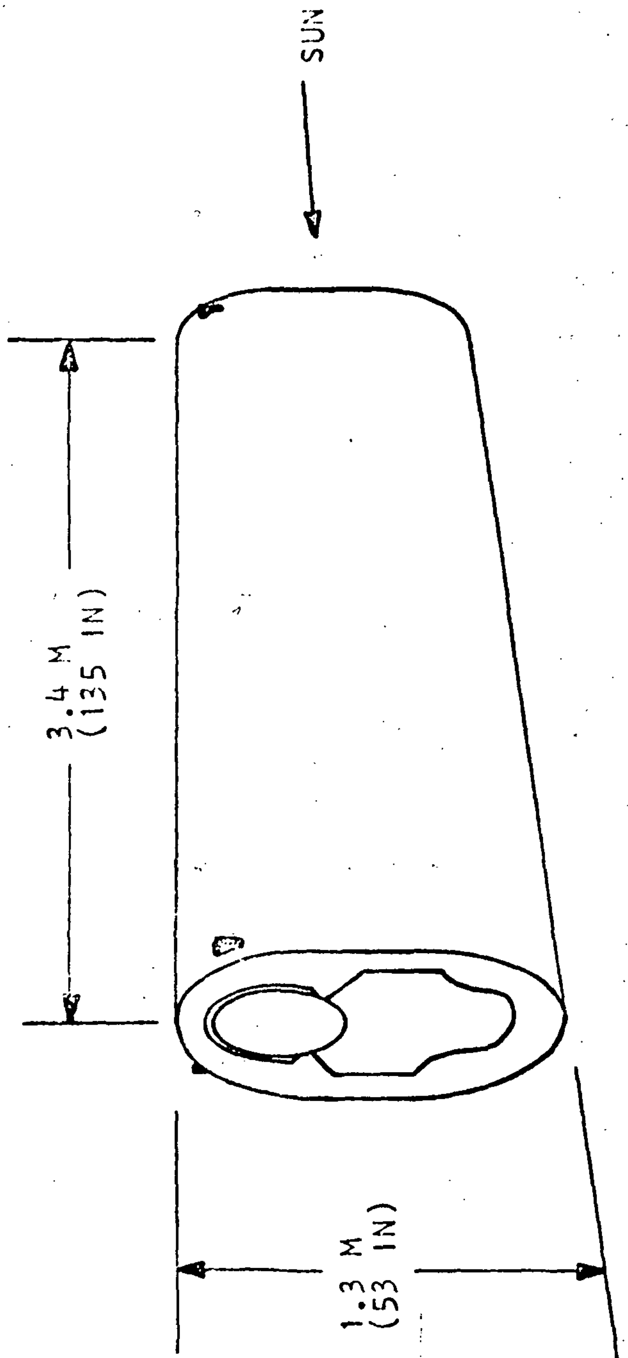

FIGURE 1 - XUV SPECTROHELIOGRAPH

• SPECTRAL COVERAGE	17 TO 65 NANOMETERS (170 TO 650Å)
• F/NUMBER	F/12 PRIMARY (AND SYSTEM)
• FIELD OF VIEW	9.3 X 10^{-3} RADIANS (32 ARC-MINUTES)
• FORMAT	28-500 MILLIMETERS (MM)
• SCALE	3.34 X 10^{-4} RADIANS/MM (69ARC-SECONDS/MM)
• ANGULAR RESOLUTION	5.8 X 10^{-6} RADIANS (1.2 ARC-SECONDS)
• SPECTRAL RESOLUTION	1.5 PICOMETERS (0.015Å)

TABLE I - PERFORMANCE CHARACTERISTICS OF THE 0.25 XUV SPECTROHELIOGRAPH

the performance characteristics for the instrument. The performance characteristics are mostly identical to the Blue Book.

The MTF curves of the SHG are given in Figure 2. A WFE of 0.05 λ rms at 633 nanometers was assumed giving 2 λrms at 17 nanometers and assuming that an aspheric grating is developed. It was also assumed that the filter introduces negligible WFE. When WFE exceeds about 0.1 rms, its effect on MTF depends on the source of error; spherical, coma, or astigmatism. It was assumed that the 2 λ rms WFE would be composed of equal portions of each error type. Figure 2 shows that WFE introduces a very large degradation from perfect performance, and that the film further reduces performance significantly. It can be seen that at least 0.1 arc-second rms image motion can be tolerated. The 0.1 arc-second rms is proposed only as a worst case possibility.

2.3 Instrument Interfaces and Characteristics

2.3.1 Equipment Interface Diagram - The equipment interface diagram is shown in figure 3. This diagram identifies the major interfaces between the spectroheliograph and the support subsystems.

2.3.2 Scientific Equipment Characteristics - Preliminary scientific equipment characteristics are listed in table II.

2.3.3 Instrument Mounting and Alignment Requirements - The complete telescope assembly is suspended within a gimbal ring. The Spectroheliograph can be grouped with other solar instruments to enable imaging and spectrometry to be performed concurrently on radiation received from any selected spot or area on the sun. The supporting vehicle or platform will provide pointing and angular stability for the grouped instruments so that images and spectra versus wavelength band may be readily correlated.

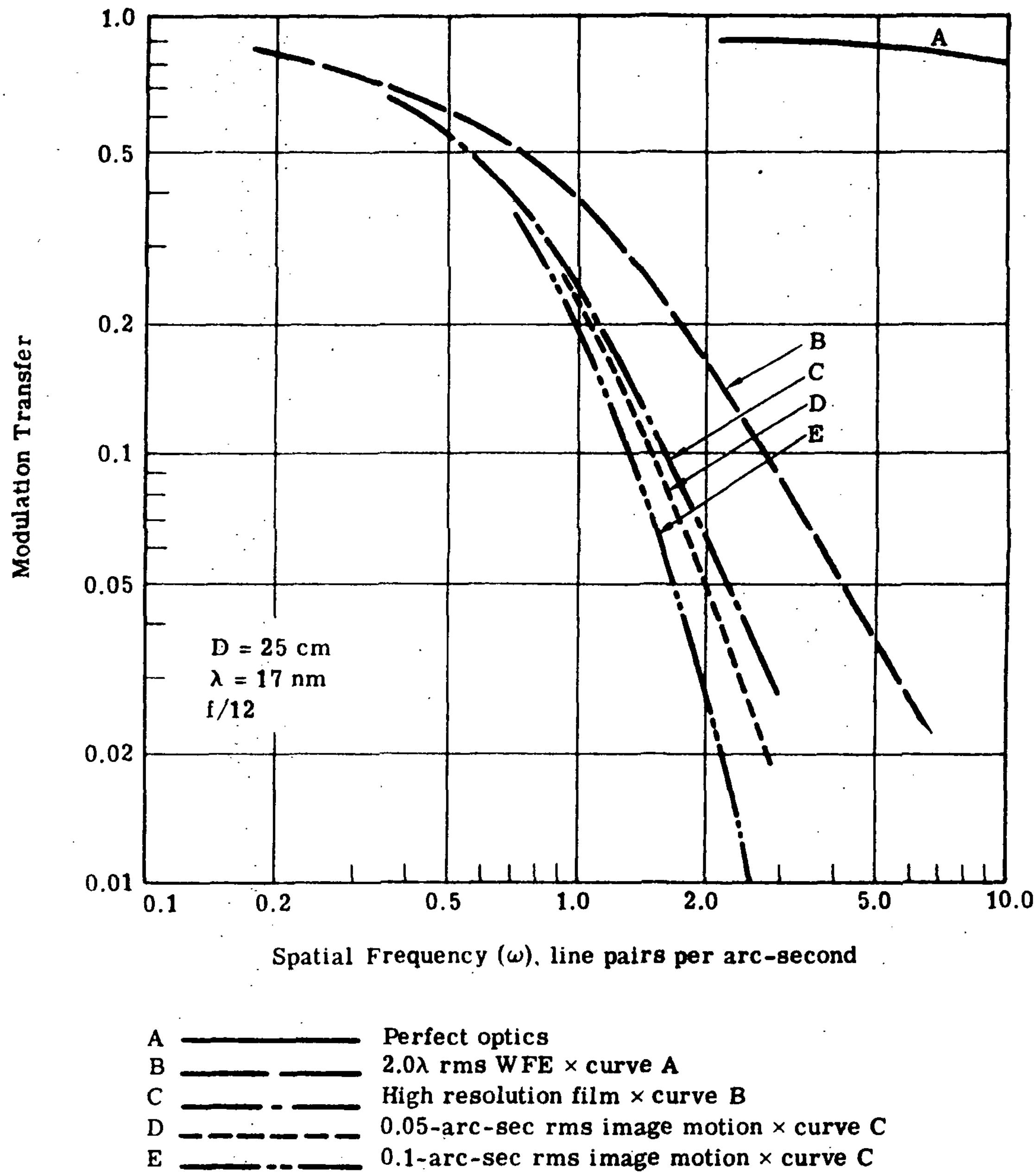

FIGURE 2 MTF ANALYSIS OF XUV SPECTROHELIOGRAPH

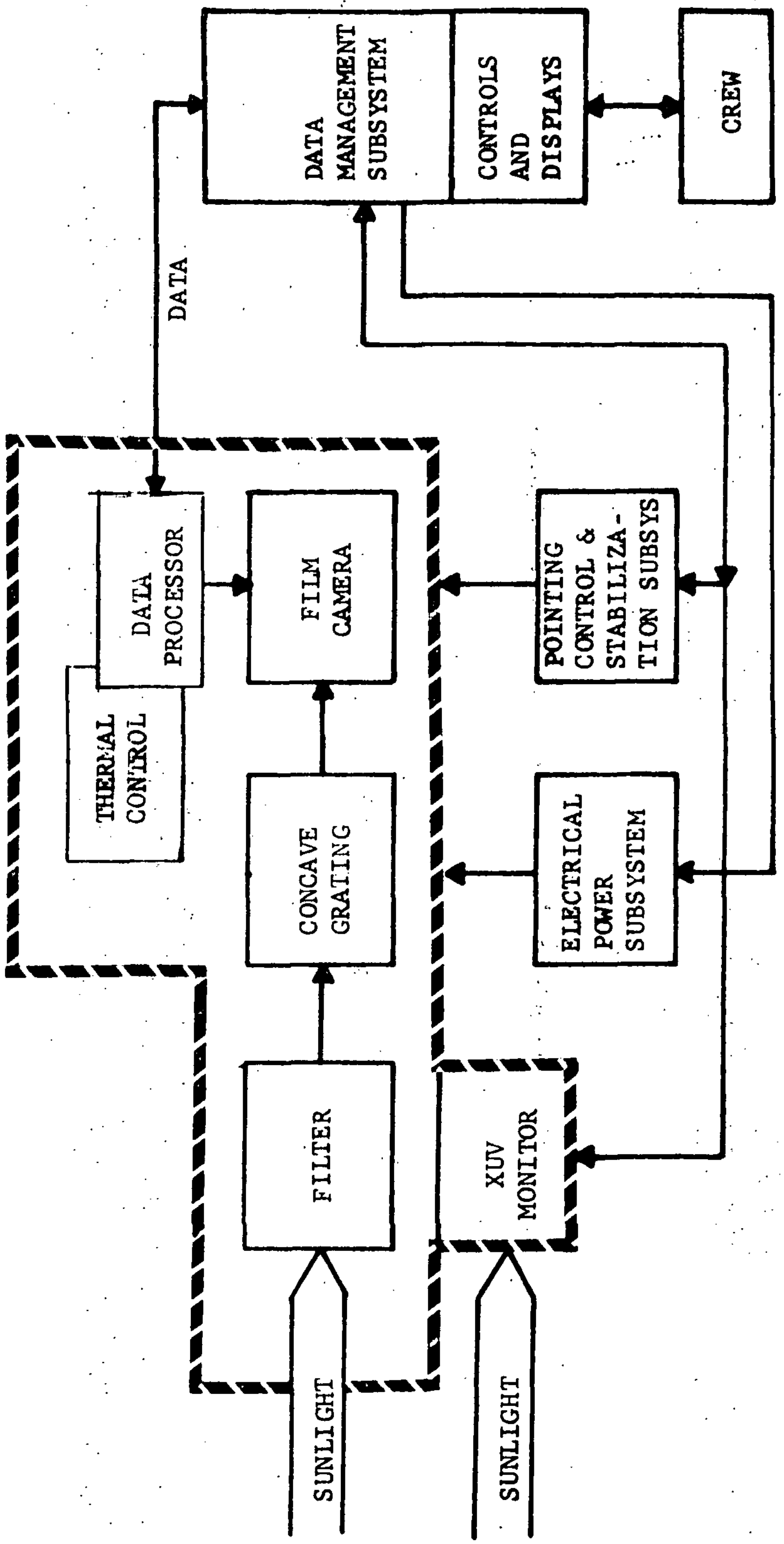

FIGURE 3 SPECTROHELIOGRAPH INTERFACE DIAGRAM

DESCRIPTION	QTY	DIMENSIONS					WEIGHT KG (LBS)	POWER, WATTS
		WIDTH, M (IN)	HEIGHT, M (IN)	LENGTH, M (IN)	DIAMETER M (IN)	VOLUME M^3 (FT^3)		
SPECTROHELIOGRAPH	1	0.76 (30)	1.3 (53)	3.4 (135)	--	3.1 (108) APPROX.	430 (945)	50 AVERAGE 60 PEAK
FILM CAMERA	1						10 (22)	4
COLLECTING OPTICS (CONCAVE GRATING)	1				0.25 (9.8)	--	15 (33)	
XUV MONITOR							56.3 (111)	12 AVERAGE

TABLE II EQUIPMENT CHARACTERISTICS

The optics, including an XUV monitor for field viewing are aligned on the ground and only minor focus adjustments are made as needed. Alignment of the telescope (through the gimbals and pallet systems) must be lined up with the vehicle reference axis within (TBD) radians. The true reference direction offsets between the telescope and the vehicle axes must be known to (TBD) radians before launch.

2.4 Operations

2.4.1 Functional Flow Diagram - A gross outline of the functions required is shown in the Functional Flow Diagram of figure 4.

2.4.2 Instrument Preparation Requirements - After the Shuttle has achieved stable orbit, and before any functions are performed with the telescope, a safety check of the telescope and support equipment is required. Covers and lens caps are removed prior to release of the equipment for operation. The (hinged) deployment boom mechanism is erected and locked. Electronic and control circuits are energized and the film system exposes a series of photographs of the plages, inner corona and various standard lamps. Calibrations will be repeated at intervals during operation depending on the frequency of photographs and the type of phenomena being observed.

2.4.3 Instrument Operation Requirements - The spectrograph will operate continually while the sun can be observed. There will be an average of one exposure every three minutes. During normal operation (e.g., quiet sun mode), the instrument will operate automatically and the crew will be required to monitor the operation infrequently. In the event of a flare, the rate of operation will be increased with the crew controlling the experiment or commanding frequent data taking to correspond to the solar activity.

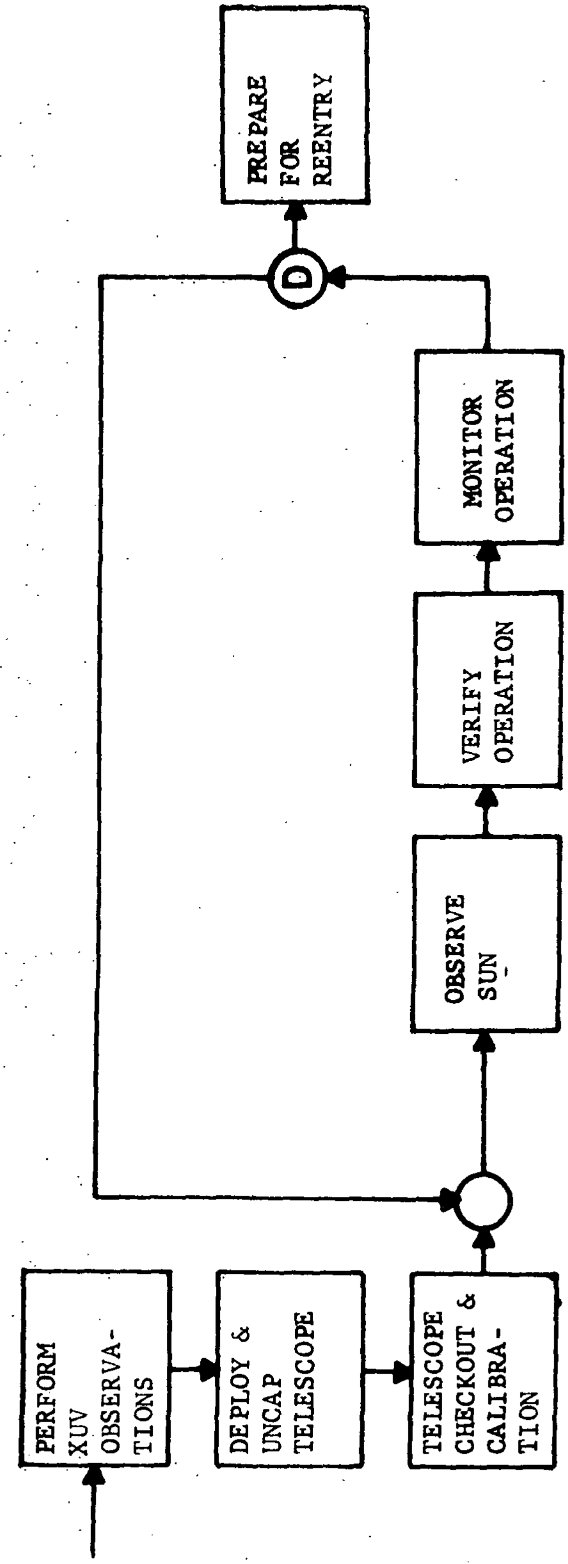

FIGURE 4 FUNCTIONAL FLOW DIAGRAM, XUV SPECTROHELIOGRAPH

2.4.4 Instrument Post-Operation Requirements - The major post-operation functions are:

a. Turn off instrument power

b. Place instrument in the caged gimbal orientation

c. Retract the instrument into the shuttle.

d. Reset the launch restraints

e. Turn off support equipment power and prepare instrument for re-entry

These operations are performed by the crew through the controls and displays console.

2.4.5 Typical Instrument Operation Timelines - The experiment operational characteristics described in the above paragraphs are summarized in Table III.

2.5 Environment - The environmental requirements and constraints associated with this instrument are listed in table IV.

2.6 Data - The scientific and engineering data generated is shown in table V.

2.7 Pointing

2.7.1 Accuracy - The pointing accuracy specification was raised from 12.1×10^{-6} radians (2.5 arc-seconds) to 73×10^{-6} radians (15 arc-seconds) since the smaller value is unnecessary for a 9.3×10^{-3} radian (32 arc-minute) field-of-view. This relaxed pointing specification should not affect mission effectiveness.

2.7.2 Stability - Pointing stability is specified at 0.49×10^{-6} radians (0.1 arc-second).

2.8 Controls and Displays - The functional requirements for the controls and displays required to operate the instrument are listed in table VI.

OPERATING SEQUENCE / SUPPORT REQUIREMENTS	INITIAL							REPEATED (5/DAY)					REPEATED (1/DAY)		FINAL			
	SAFETY CHECK	INITIAL POWER UP	RELEASE LAUNCH LOCKS AND DEPLOY	OPEN COVER AND LENS CAP	ACQUIRE SUN	CALIBRATE-SUN SOURCE	CALIBRATE-STANDARD LAMPS	OBSERVE ACTIVE SUN	VERIFY OPERATION	OBSERVE QUIET SUN/FLARES	VERIFY OPERATION	MONITOR DATA ACQUISITION	CALIBRATE-SUN SOURCE	CALIBRATE-STANDARD LAMPS	CLOSE LENS CAP AND COVER	RETRACT TELESCOPE AND SECURE LAUNCH LOCKS	POWER DOWN ELECTRONICS	SUBSYSTEM POWER OFF
TIME MINUTES	2-20	30	34	11	19	30	30	20	6	264	6	12	10	18	30	70	4	2
CREW PARTICIPATION	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X
SPECTROHELIOGRAPH	X	X	X	X	X										X	X	X	X
FILM CAMERA						X	X	X	X	X	X	X	X	X				
(CONTROL & DISPLAYS)		X	X	X	X	X	X		X		X	X	X	X	X	X	X	X
(GIMBALLED MOUNT)	X	X	X		X	X		X		X			X			X		X
POWER PROFILE (WATTS) INSTRUMENT	50 — 50; 60 (PEAK DURING FILM CHANGE)																	
DATA PROFILE (BPS)	--	10	10	10	60	60	60	60	60	60	60	60			60	10	--	--

TABLE III EXPERIMENT OPERATIONAL CHARACTERISTICS

	OPERATING	NON-OPERATING
MECHANICAL		
o Vibration	Vibration loads must not cause deflections within the instrument greater than TBD microradians.	With launch locks set, stands launch and reentry loads.
o Acceleration	g-loads must not cause deflection within the instrument greater than TBD microradians (less than 10^{-4}g)	With launch locks set, stands launch and reentry loads
o Acoustics	N/A	TBD
THERMAL	$290^{o}K$ to $294^{o}K$;	$253^{o}K$ to $309^{o}K$
ATMOSPHERIC		
o Humidity	Less than 10%	Less than 40%
o Pressure	0 to 10^5 N/m^2 (0 to 15 psi)	0 to 10^5 N/m^2 (0 to 15 psi)
o Contamination	Sensitive	(Telescope covered)

TABLE IV ENVIRONMENTAL REQUIREMENTS AND CONSTRAINTS

CLASS	DESCRIPTION	FORMAT	READOUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION	COMMENTS
SCIENTIFIC								
	FILM STRIP, 35 MM	28-500 MM	ONE STRIP/ THREE MINUTES		(AVERAGE)		N/R	
	XUV MONITOR TELESCOPE	DIGITAL (ANALOG)	(CONTINU-OUS FOR GUIDANCE MONITOR)	$7X10^6$ BPS (11 MHZ)	100%			
ENGINEERING	EXPERIMENT EQUIPMENT	DIGITAL	CONTINU-OUS	50 BPS	100%		N/R	
	SUPPORT EQUIPMENT	DIGITAL	CONTINU-OUS	10 BPS	100%		N/R	

TABLE V SPECTROHELIOGRAPH DATA REQUIREMENTS

Function	Component	
	Control	Display
Main Power	Toggle SW	SW Pos
Aperture Door	Toggle SW	Status Lt
Launch Locks	Toggle SW	SW Pos
Thermal Control	Toggle SW	SW Pos
Wavelength Select	Toggle SW	SW Pos
Exposure Duration	Toggle SW	SW Pos
Flare Mode	Toggle SW	SW Pos
Mode Select	Rotary SW	SW Pos
Data Status	Toggle SW	
		Status Lt
Camera Power	Toggle SW	SW Pos
Vidicon HV	Toggle SW	SW Pos
Display		TV Monitor
Frames Remaining		5 Digit Counter
Frame Rate	Toggle SW	SW Pos
Camera Status	Toggle SW	
		Status Lt

TABLE VI PRELIMINARY FUNCTIONS AND C&D COMPONENTS FOR XUV SPECTROHELIOGRAPH

2.9 Preflight/Postflight Ground Support - The major ground facility and equipment requirements are listed in table VII.

2.10 Post-Mission Refurbishment - The instrument will require refurbishment of the film cameras and the normal calibration and alignment sequences before flight.

2.11 Orbital Parameters - Continuous sun viewing for six days is desired for the spectroheliograph. The minimum altitude for any inclination is that required for continuous sun viewing with an earth atomsphere of 185 kilometers (100 nautical miles).

3. PROGRAMMATICS

3.1 Equipment Cost and Schedule - Schedule and cost estimates for the spectroheliograph are given in Table VIII.

3.2 Safety Considerations - There are no pyrotechnic or explosive devices required for this telescope. The film magazine will be capable of containing sufficient film for the seven day sortie mission to preclude extravehicular activity.

3.3 Reliability - Equipment reliability will depend on the level of effort devoted to reliability during design, development, fabrication and test phases of the equipment.

4. NOTES

4.1 Bibliography - This BEDD contains information from the following documents. No reference to the documents is made in the text.

a. Reference Earth Orbital Research and Applications Investigations (Blue Book), Volume II - Astronomy, January 15, 1971.

b. Orbital Astronomy Support Facility (OASF) Study, NAS8-2103, McDonnell Douglas Corporation, Huntington Beach, California, 28 June 1968.

	Before Flight	During Flight	After Flight
1. Functions	1. Transportation 2. Receiving 3. Inspection 4. Handling 5. Storage 6. Installation and Assembly 7. Test and checkout 8. Alignment and Servicing 9. Interface Verification	1. Coordinate with Astronaut/Astronomer to change observing schedule	1. Post-Flight Checkout 2. Equipment Refurbishment 3. Data Distribution
2. Equipment	1. Shipping Container Including Environment Control 2. Handling Fixtures 3. Test and Checkout Equipment 4. Alignment Fixtures and Tooling (optical lab) 5. Clean Room, Class 100,000		Same as Preflight
3. Other	1. Ground Support Procedures 2. Dry Nitrogen Purge		

TABLE VII GROUND SUPPORT REQUIREMENTS

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)		(0.35)	(0.70)	(0.60)	(0.50)			$ 2.15
PRODUCTION-FIRST ARTICLE				(0.30)	(0.40)	(0.30)		1.00
								$ 3.15

TABLE VIII - SCHEDULE AND COST ESTIMATES, 25·CM XUV SPECTROHELIOGRAPH

2.3 X-RAY TELESCOPE (XRT)

ASM-EXP-204-1
August 28, 1972

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

Baseline Experiment Definition Document (BEDD): ASMDS X-Ray Focusing Telescope

Contract GC1-115076

Prepared by:

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Approved by:

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Project Manager

The Bendix Corporation
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CONTENTS

CONTENTS (Continued)

1. INTRODUCTION

This document defines a baseline X-ray Focusing Telescope instrument for the Astronomy Sortie Missions Definition Study.

The scientific objectives, equipment description, physical interface requirements, functional and procedural interfaces, and programmatic estimates are identified.

2. DISCUSSION

2.1 Scientific Objectives - The objectives of the X-ray Focusing Telescope are to observe solar radiation and phenomena in the 0.2 to 10 nm (2 to 100 Å) wavelength region, and to obtain measurements with high spatial, spectral, and temporal resolution.

The instrument is primarily designed for solar observations, but could be used for high-resolution observations of bright discrete stellar X-ray sources. Only minor instrument modifications would be required for non-solar observations.

2.2 Instrument Description - The solar X-ray Focusing Telescope consists of a grazing incidence telescope, with three detector units. Ancilliary experiment support units are also required. An outline drawing of the telescope and detectors is shown in Figure 1. The telescope provides a high resolution X-ray image at the focal plane of a grazing-incidence objective system. Plate scale of the image is approximately 0.3 milliradian per millimeter (1 arc minute per millimeter).

Any one of the three detector units can be placed at the focal plane, to provide specific scientific observations. The detectors are: an imaging camera, a curved-crystal spectrometer, and a proportional counter spectrometer.

The imaging camera, consisting of an image intensifier/converter, a film camera (or electronic image tube camera), and programming electronics, will provide high spatial resolution images,

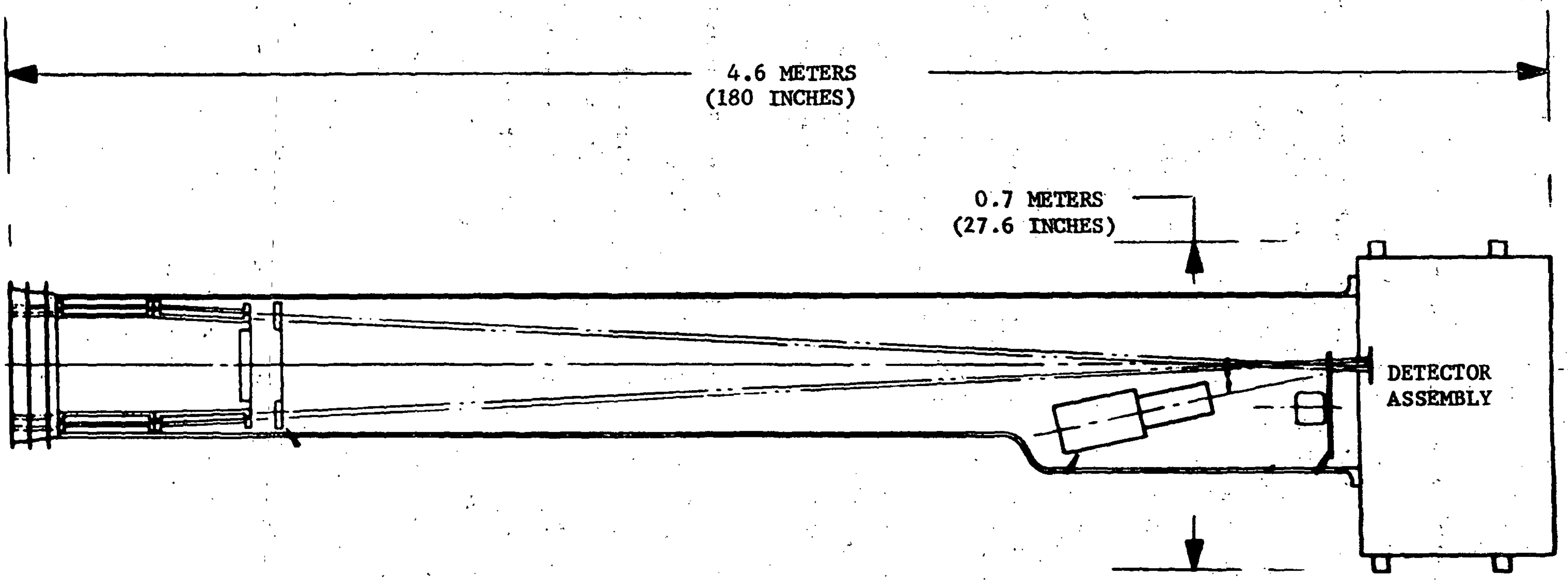

FIGURE 1 - X-RAY FOCUSING TELESCOPE

with medium spectral and temporal resolution.

The curved-crystal spectrometer, consisting of a slit, a focusing Bragg-reflecting crystal, a proportional counter detector, and a spectral scan drive mechanism will provide high spectral resolution observations of small regions; the spatial resolution is defined by the dimensions of the slit.

The proportional counter will provide observations with high temporal resolution, and will also utilize the slit to provide spatial resolution. Coarse wavelength range selection is provided by a filter wheel, as with the other two detector units. Moderately good spectral resolution is obtained in the proportional counter unit by pulse-height analysis.

A summary of the detector resolution characteristics is shown in Table I. The detector units do not operate simultaneously; only one detector unit can be placed at the focal plane at one time. Selection of the detector to be used for a specific observation is made by the scientific crewman.

To help the scientific crewman carry out the observation programs, he is provided with several auxiliary displays:

1. A scintillation-crystal/photomultiplier tube unit that measures the integrated solar activity in the 1.3 to 13 fJ range (8 to 80 KV, 0.15 to 1.5Å). This unit supplies data for control of camera exposure durations and rates; it is possible to use this unit for automatic camera exposure control during solar flares.

2. An H-alpha slit camera display, which views the solar image reflected from the (slightly tilted) front surface of the slit used for the crystal spectrometer and the proportional counter spectrometer. This display will assist in satisfying the target acquisition requirements of the two spectral detector units.

3. A small X-ray telescope which provides an image of the complete sun in X-rays, to identify regions of high activity on

Table I. Detector Resolution Summary

DETECTOR		RESOLUTION	
	SPATIAL (μrad)	SPECTRAL ($\lambda/\Delta\lambda$)	TEMPORAL (sec)
Imaging System	< 5	< 2	$\sim$ 1
Crystal Spectrometer	10 to 50	$\sim 2\times10^3$	> 100
Proportional Counter	10 to 50	< 2	< 0.01

the sun.

4. A full-sun H-alpha monitor telescope, to facilitate target recognition and acquisition, and provide a reference for observational input requests from ground-based supporting scientists.

2.3 Equipment Interfaces and Characteristics

2.3.1 Experiment Interface Block Diagram - The experiment interface block diagram is shown in Figure 2. This diagram identifies the major interfaces between the experiment and spacecraft subsystems.

2.3.2 Equipment Characteristics - Estimated experiment and support equipment characteristics are shown in Table II and Table III, respectively.

2.4 Operational Requirements

2.4.1 Functional Flow Block Diagram - An experiment functional block diagram is shown in Figure 3. This diagram shows the various possible sequences of experiment operation.

2.4.2 Observational Requirements - The experiment observational requirements are listed in Table IV.

2.4.3 Typical Operation Timelines - A summary of experiment operational requirements is shown in Table V. The table shows a typical timeline of orbital events beginning with orbital sunrise and ending part way through the next orbital light period. Experiment and support equipment usage is indicated. Also gross power, data, and stability timelines are shown.

2.5 Environmental Requirements/Constraints - The experiment environmental requirements and constraints are listed in Table VI.

2.6 Data - The primary scientific data is described in Table VII, together with the auxiliary data required. This complete data package represents the basic information which will be used to achieve the specified scientific objectives of the instrument.

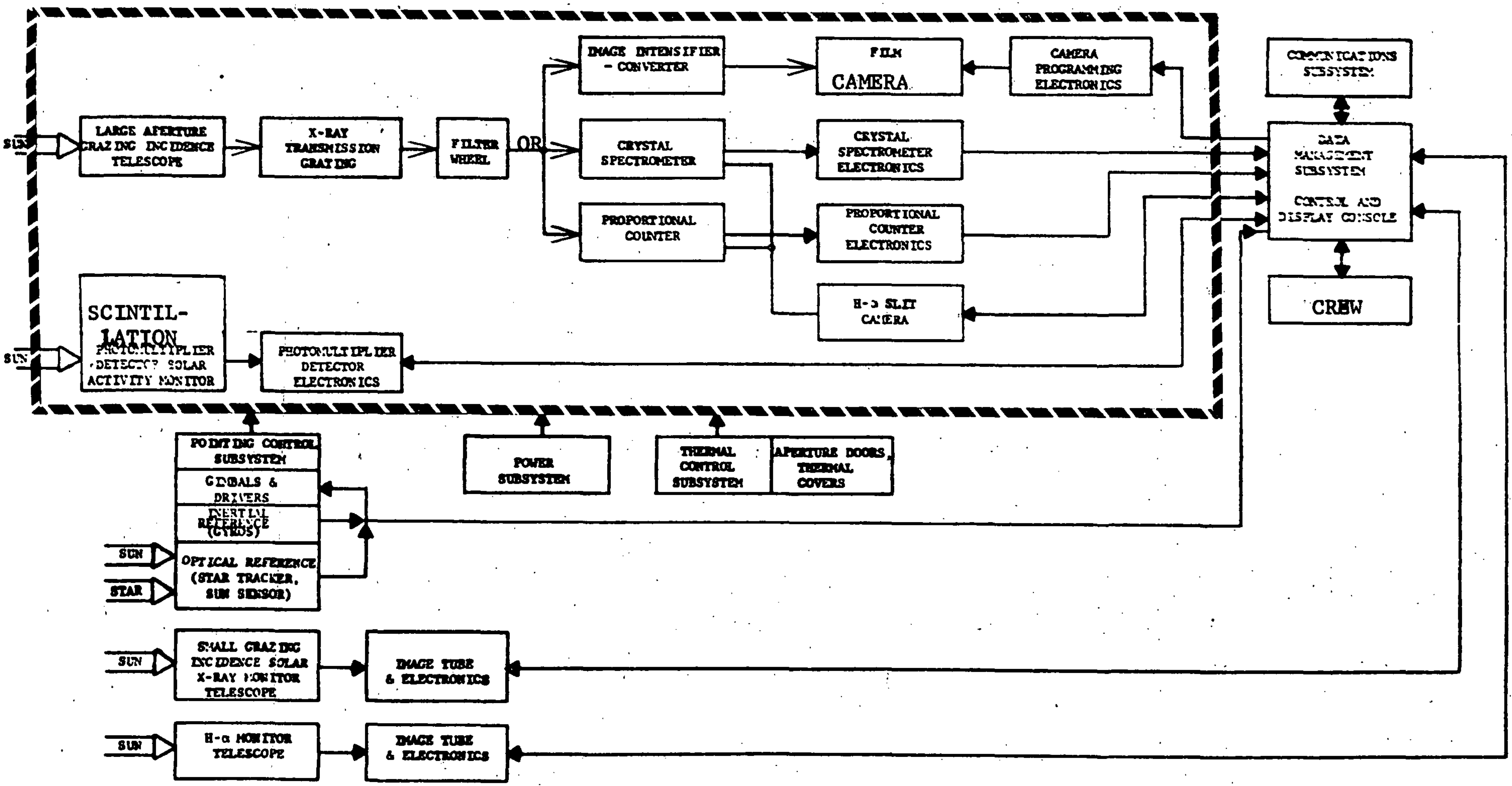

Figure 2. X-Ray Focusing Telescope Interface Block Diagram

Table II. Experiment Equipment Characteristics

DESCRIPTION	QTY	WIDTH	HEIGHT	LENGTH	DIAMETER	VOLUME,	WEIGHT	DATA, kbps	POWER, WATTS
X-Ray Telescope	1			(180 in.)	(26 in.)		(450 lb)	-----	10 Average 50 Peak (1 min)
Grating	1	(12 in.)		(6 in.)	(24 in.)		(25 lb)	-----	20 Peak Only (50 msec)
Image Intensifier Film Camera	1	(5 in.)	(18 in.)	(15 in.)			(40 lb)	-----	10 Average 20 Peak (50 msec)
Crystal Spectrometer	1	(5 in.)	(18 in.)	(20 in.)			(40 lb)	10	30 Average
Proportional Counter	1	(4 in.)	(10 in.)	(12 in.)			(15 lb)	2	20 Average
Electronics Assembly**	1	(12 in.)	(24 in.)	(24 in.)		4.0 cu ft	(50 lb)	15 max)	50 Average
Scintillation Detector	1	(3 in.)	(3 in.)	(18 in.)			(20 lb)	-----	10
H-α Slit Camera	1	(4 in.)	(4 in.)	(12 in.)			(10 lb)	-----	10

Volume and Weight Total (ENG): (37 cu ft) (650 lb)

**Can Be Mounted Remotely From Telescope

***Detectors Are Operated Sequentally; Data Buffered by Electronics Assembly

NOTE: SI units TBS.

Table III. DIRECT SUPPORT EQUIPMENT CHARACTERISTICS

DESCRIPTION	QTY	WIDTH	HEIGHT	LENGTH	DIAMETER	VOLUME	WEIGHT	DATA, kbps	POWER. WATTS
Grazing Inc. Monitor Tel.	1			(48 in.)	(8 in.)		(100 lb)	---	10 Average
H-α Monitor Telescope	1			(60 in.)	(10 in.)		(110 lb)	---	10 Average
Gimballed* Mount	1	TBD		TBD			TBD	TBD	~200 Peak (When In Use)

*Includes Inertial And Optical Reference Sensors

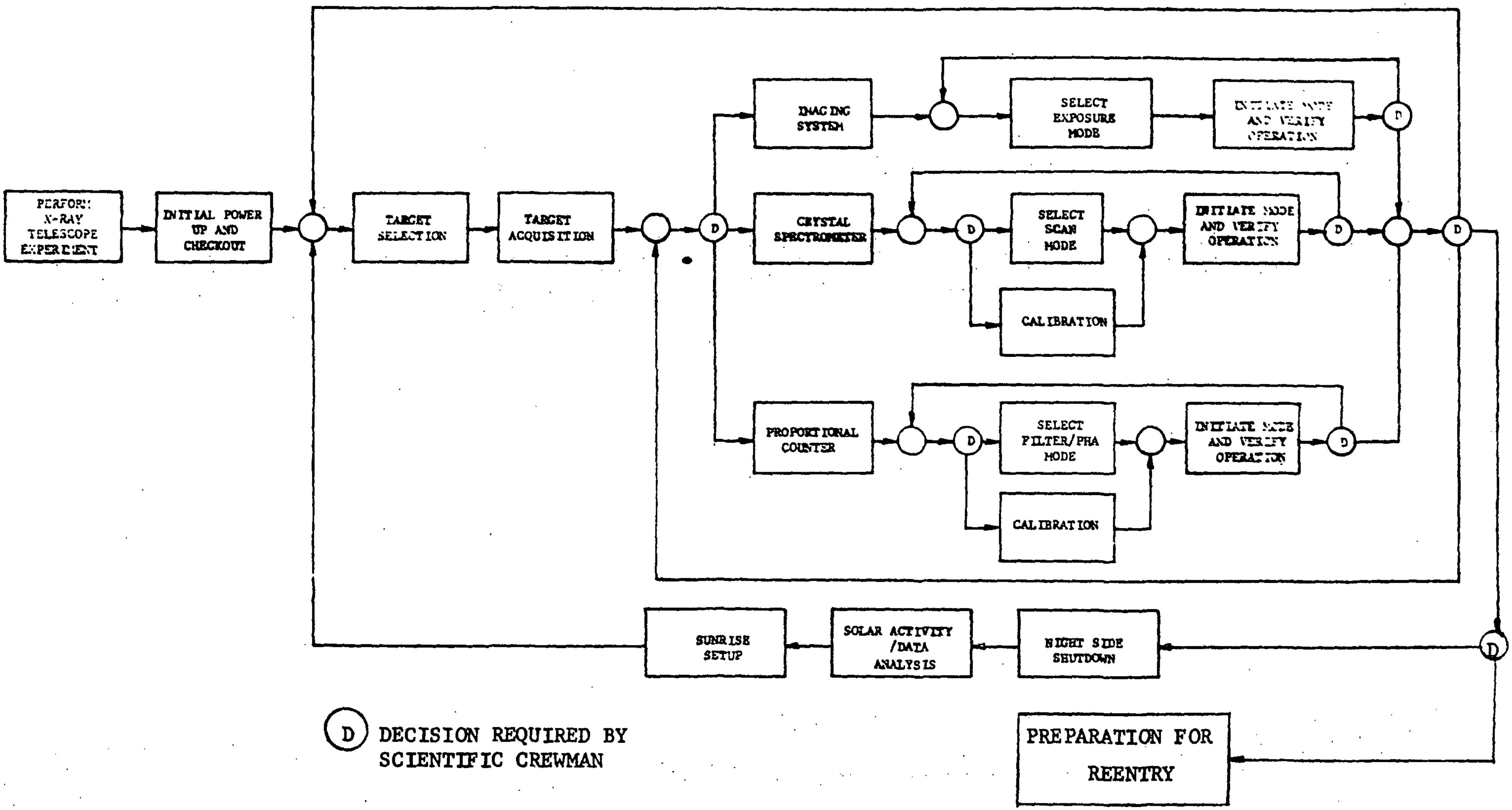

Figure 3. X-Ray Focusing Telescope Functional Block Diagram

Table IV. Experiment Observational Requirements

DETECTOR	MODE		
	QUIET SUN	ACTIVE SUN	FLARE
Imaging System	4 Sets/Day 24 Exposures/Set 5 Minutes/Set	2 Sets/Active Region 2 Active Regions/Day 5 Minutes/Set	Time Share All Flares With Other Instruments
Transmission Grating	None	4 Sets/Active Region 1 Active Region/Day 5 Minutes/Set	Time Share All Flares With Other Instruments
Crystal Spectrometer	150 Scans/Mission 3 Minutes/Scan	150 Scans/Mission 3 Minutes/Scan	None
Proportional Counter	None	200 Samples/Mission 0.5 Minutes/Sample	Time Share All Flares With Other Instruments

Table V. Typical Experiment Operating Timelines

	Experiment Operating Sequence / Support Requirements	Initial Power-Up and Checkout	Initial Sunrise Setup	Target Selection (Quiet Sun)	Target Acquisition	Operate Imaging System	Index To Crystal Spectrometer	Operate Crystal Spectrometer	Target Selection (Active Region)	Target Acquisition	Operate Crystal Spectrometer	Index To Imaging System	Operate Imaging System	Index Grating In	Operate Imaging System + Grating	Index To Proportional Counter	Operate Proportional Counter	Target Selection (Active Region)	Target Acquisition	Operate Proportional Counter	Initiate Dark Side Standby
		Initial	Repeated																		
	Minutes		5	3	3	5	1	3	3	3	3	1	5	1	5	1	1	3	3	1	1
Crew Requirements	Solar Astronomer/Physicist																				
Experiment Equipment Operational Requirements	X-Ray Telescope	X	X		X	X	X	X		X		X	X		X		X			X	X
	Grating	X	X											X	X						X
	Imaging System	X	X			X						X	X		X						X
	Crystal Spectrometer	X	X				X	X			X										X
	Proportional Counter	X	X													X	X			X	X
	Electronics Assembly	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Photomultiplier Detector	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	H-α Slit Camera	X	X					X		X	X						X		X	X	
Support Equipment Operational Requirements	X-Ray Monitor Telescope	X	X	X	X				X	X								X	X		X
	H-α Telescope	X	X	X	X				X	X								X	X		X
	Gimballed Mount	X	X		X					X									X		X
Time - Dependent Functions	Power Profile 160 W Continuous Plus Peaks As Shown				200	20	40			200		40	20	20	20	40			200		
	Data Profile (kbps)							10			10						2			2	
	Target				← Quiet Sun →							← Active Region →							← Active Region →		
	Stability 0.5 sec									X	X						X		X	X	
	Stability 0.1 sec				X	X							X	X							
	Remarks		Data Profile Is Experiment Housekeeping (100 bps) Plus Peaks As Shown																		

	Experiment Operating Sequence / Support Requirements		Enter Dark Side	Solar Activity/ Data Analysis		Initial Sunrise Setup	Target Selection (Active Region)	Target Acquisition	Operate Proportional Counter	Index To Crystal Spectrometer	Operate Crystal Spectrometer	Flare Alert	Target Identification	Target Acquisition	Index To Imaging System & Grating	Operate Imaging System & Grating	
		Repeated															Termination
	Minutes					5	3	3	1	1	2	X	1	3	1	Flare Duration	
Crew Requirements	Solar Astronomer/Physicist																
Experiment Equipment Operational Requirements	X-Ray Telescope					X		X	X	X	X			X	X	X	
	Grating					X									X	X	
	Imaging System					X									X	X	
	Crystal Spectrometer					X				X	X						
	Proportional Counter					X			X								
	Electronics Assembly					X	X	X	X	X	X	X	X	X	X	X	
	Photomultiplier Detector					X	X	X	X	X	X	X	X	X	X	X	
	H-α Slit Camera					X		X	X		X						
Support Equipment Operational Requirements	X-Ray Monitor Telescope					X	X	X					X	X			
	H-α Telescope					X	X	X					X	X			
	Gimballed Mount					X		X						X			
Time - Dependent Functions	Power Profile 160 W Continuous Plus Peaks As Shown							200		40				200	40	20	
	Data Profile (kbps)								2		10						
	Target								← Active Region →						← Flare →		
	Stability 0.5 sec							X	X		X						
	Stability 0.1 sec													X		X	
	Remarks																

Table VI. Environmental Requirements/Constraints

		OPERATING	NONOPERATING
MECHANICAL	Acceleration	$< 2\ m\ sec^{-2}$	With launch restraints set, withstands peak values defined for normal launch and reentry.
	Vibration	TBD	
	Acoustic	TBD	
THERMAL	Absolute temperature limits	Instrument: 290 to 294^{o}K Aperture door and reflecting baffles required at Solar end. Thermal shielding and heaters required for telescope and detectors.	Instrument: 253 to 309^{o}K
	Differential temperature limits	$T < 1^{o}$K across grazing incidence mirror system.	$T < 2^{o}$K across telescope tube or detector units.
ATMOSPHERE	Pressure	$10^{-4}\ N\ m^{-2}$	$< 1.2\times10^{5}\ N\ m^{-2}$
	Humidity	-	Crystal in spectrometer requires RH < 10%.
	Contaminants	Extremely susceptible to degradation by oils and other organic materials.	Clean-room type environment required, class 10000 or better. Must maintain clean dry nitrogen purge during storage.
EXTERNAL INTERFERENCES	Magnetic Fields	$< 2\times10^{4}$ tesla at detector units.	TBD
	RF fields	$< 10^{-TBD}\ V\ m^{-1}$, $< 10^{-TBD}\ W\ m^{-2}$	TBD
	Ionizing particles	< 0.01 count sec^{-1} in detector units. Detectors will require power down in high flux conditions such as South Atlantic Anomaly (SAA) crossings.	Crossings through South Atlantic Anomaly must not generate delayed radioactivity in surrounding equipment and structures.

Table VII. Recorded Data Requirements

CLASS	DESCRIPTION	FORMAT	READ-OUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION(2)
SCIENTIFIC							
a. Camera	Images of selected solar features through spectrally-selective filters	Film, with data block reference annotations	up to one frame per second	as required	as required	up to 5000 frames per mission	N/A
b. Proportional counters	Spectrally sorted counts received from small solar region	digital 20 bit	100 sec^{-1}	2000 bps	as required	up to 200 Mbits	20:1
c. Crystal spectrometer	counts of pulses	digital 20 bits	100 sec^{-1}	2000 bps	as required	up to 400 Mbits	20:1
INSTRUMENT HOUSEKEEPING	100 readout points, commutated sampling	digital 8 bit	1 sec^{-1}	8 bps	Continuously after instrument turned on (1)	4 Mbits	1:1
CREW'S ANNOTATION	Voice comments Logbook entries	"analog" written	as required	BW >1 kHz	(1)	120-144 hours	
SUPPORT EQUIPMENT:							
Scintillation Detector	Pulse amplitude + code	digital 12 bit	10 sec^{-1}	120 bps	(1)	60 Mbits	1:1
SUBSYSTEMS:							
Spacecraft Angles/Attitude	IMU signals	digital 3x15 bit	0.01 sec^{-1}	0.45 bps	(1)		
Gimbal Angles	Angular encoders	digital 2x15 bit	0.05 sec^{-1}	1.5 bps	(1)		
Rate Gyros	Angular rates	digital 2x10 bit	0.5 sec^{-1}	10 bps	(1)	16 Mbits	1:1
Timing	Clock reference	digital 20 bit	1 sec^{-1}	20 bps	(1)		

NOTES: (1) Equipment is operating and data is recorded at all times between turn-on and shutdown. Recording continues even if not observing a specific source.

(2) Only data buffering is considered, using simple storage, processing and coding techniques. Further compression can be achieved with standard compression algorithms.

In addition to the recording of this data, it must be available for real-time monitoring at the Controls and Displays Console, as defined in 2.8.

The possibility of in-flight support by ground-based scientific personnel must be included. Ground support of this type will interface with the observation crew, through the voice link. It is anticipated that all commands to the scientific and support equipment will be performed by the observation crew, through the controls and displays console.

Reference timing signals must be available with the scientific and support data. It must be possible to correlate this data with GMT to within an absolute accuracy of less than 1 msec.

2.7 Pointing and Stability - The pointing accuracy requirement for the telescope is 1×10^{-4} radians (20 arc-seconds). The scientific crewman is used to perform coarse pointing and to close the pointing loop. The requirement for pointing stability is set at 0.49×10^{-6} radians (0.1 arc-second) since the resolution at the center of the field will be approximately 2.4×10^{-6} radians (0.5 arc-second).

2.8 Controls and Displays - The functional requirements for the controls and displays required to operate the instrument are listed in Table VIII.

2.9 Preflight/Postflight Ground Support - The ground support requirements are listed. These include equipment and facilities and a brief discussion of the major functions required after instrument installation.

2.9.1 Ground Support Equipment and Facilities - The major facility and equipment requirements are listed in Table IX.

2.9.2 Test, Checkout and Calibration - After instrument installation is complete according to established interface requirements, test and checkout of the complete experiment system as an

Table VIII. Preliminary Functions and C&D Components

FUNCTION	COMPONENT	
	CONTROL	DISPLAY
<u>GENERAL</u>		
Main Power	Toggle Switch	Switch Position
Thermal Control	Toggle Switch	Status Light
Aperture Door	Toggle Switch	Status Light
Filter Select	Rotary Switch	Switch Position
Detector Select	Toggle Switch	Switch Position
Launch Locks	Toggle Switch	Switch Position
<u>IMAGING SYSTEM</u>		
Frame Rate	Rotary Switch	Switch Position
Exposure Range	Rotary Switch	Switch Position
High Voltage	Toggle Switch	Switch Position
Grating Position	Toggle Switch	Status Light
Frames Remaining	--	5-Digit Counter
Data Status	Toggle Switch	Status Light
<u>SPECTROMETER</u>		
Slit Size	Rotary Switch	Switch Position
Scan Range (Upper)	Rotary Switch	Switch Position
Scan Range (Lower)	Rotary Switch	Switch Position
Scan Rate	Rotary Switch	Switch Position
Scan Step Size	Rotary Switch	Switch Position
Scan Sequence	Toggle Switch	Switch Position
Scans Completed	--	4-Digit Counter
Data Status	Toggle Switch	Status Light
Crystal Position	--	4-Digit Counter
Calibration	Toggle Switch	Status Light
Crystal Spectrum	Toggle Switch	Strip Chart
Detector Rate	--	Digital (4)
<u>PROPORTIONAL COUNTER</u>		
HV Power	Toggle Switch	Switch Position
Calibrate	Toggle Switch	Status Light
Aperture Size	Rotary Switch	Switch Position
PHA Resolution	Rotary Switch	Switch Position
Data Status	Toggle Switch	Status Light
Detector Rate	Toggle Switch	Digital (4)
PHA Spectrum	Toggle Switch	Strip Chart

Table VIII. (Continued)

FUNCTION	COMPONENT	
	CONTROL	DISPLAY
<u>H-ALPHA SLIT CAMERA</u>		
H-Alpha Filter Heater	Toggle Switch	Status Light
H-Alpha High Voltage	Toggle Switch	Switch Position
H-Alpha Slit Camera-Display		TV Monitor
<u>SCINTILLATION DETECTOR</u>		
Photomultiplier H.V	Toggle Switch	Switch Position
PM Intensity Data	Toggle Switch	Digital (4)
Discriminator Level	Rotary Switch	Switch Position
Flare Alert	Toggle Switch	Status Light

Table IX Ground Support Requirements

	BEFORE FLIGHT	DURING FLIGHT	AFTER FLIGHT
1. Functions	1. Transportation 2. Receiving 3. Inspection 4. Handling 5. Storage 6. Installation and Assembly 7. Test and Checkout 8. Alignment and Servicing 9. Interface Verification	Continuous Solar Patrol	1. Post-Flight Checkout 2. Equipment Refurbishment 3. Data Distribution
2. Equipment	1. Shipping Container Including Environment Control 2. Handling Fixtures 3. Test and Checkout Equipment 4. Alignment Fixtures and Tooling 5. Clean Room		Same as Preflight
3. Other	1. Ground Support Procedures 2. Dry Nitrogen Purge	Solar Forecast	

10-

integral package is required. The procedure for these operations is not defined. Some of the operations that will definitely be required can be identified:

A. Signal test of the non-imaging detectors, monitored at the data recording point.

B. Operational verification of the gimbal/telescope system for slewing rates and accuracies of pointing.

A final calibration of the detector characteristics is required prior to launch, and repeated after the instrumentation returns from orbit and before it is dismantled.

2.9.3 Accessibility Requirements - After prelaunch checkout and calibration, access is not required to the scientific equipment. Should the instrument be subjected to environments outside those specified in Table IV, a verification of instrument health will be required.

2.10 Post-Mission Refurbishment - The scientific equipment will require refurbishment of the camera and normal calibration operations before reflight.

2.11 Orbital Parameters - For this instrument, it would be advisable to avoid the detrimentral effects caused by energetic particles which populate the South Atlantic Anomaly. The South Atlantic Anomaly's geographic location is such that it can only be avoided by selecting low inclination (nearly equatorial) orbits, which are not within the capabilities of the shuttle carrier.

Continuous sun viewing for six days is desired. The minimum altitude for any inclination is that required for continuous sun viewing with an (assumed) Earth atmosphere of 185 Kilometers (100 nautical miles).

3. PROGRAMMATICS

The information in this section consists mostly of subjective estimates which are generally not supported, and probably cannot be supported, by any extensive analysis. Personal experiences with simpler instrumentation have been used for extrapolation into vastly different equipment characteristics.

3.1 Equipment Cost and Schedule - The design, development and fabrication of the ASM X-ray Telescope will be substantially based on the experience gained with the two solar X-ray telescopes in the Skylab ATM. This instrument is, however, much more sophisticated than the ATM telescopes. The ASM telescope incorporates larger mirrors, tighter mirror figure and alignment tolerances, and advanced detection instrumentation. These features provide the ASM telescope with superior scientific data acquisition capabilities, but they are costly to implement, and increase system complexity. Advanced instrumentation is also difficult to maintain in peak operating efficiency or alignment, which adversely affects the reliability of achieving the full capability of the instrument.

The schedule and cost estimates shown in Table X assume extensive design effort to achieve adequate equipment reliability for 7-day or 15-day missions, with multiple alternative operating modes, albeit with reduced performance.

3.2 Safety Considerations - As currently designed, all the scientific equipment and the majority of the support equipment (except for the controls and displays console and the data management subsystem's tape recorder) are located outside the crew compartment. There are no pyrotechnic or explosive devices required for this instrumentation. Extravehicular activity is not considered for this program.

3.3 Reliability - Mean-Time-Between-Failure (MTBF) estimates for the X-ray telescope equipment are shown in Table XI. Note that the three detector units (camera, crystal spectrometer and proportional counter spectrometer) operate sequentially, not simultaneously.

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)	(0.50)	(2.15)	(5.30)	(6.50)	(2.50)	(0.70)		$ 17.65
PRODUCTION-FIRST ARTICLE				(1.10)	(4.30)	(2.80)		8.20
								$ 25.85

TABLE X - SCHEDULE AND COST ESTIMATES, X-RAY TELESCOPE

Table XI

Mean-Time-Between-Failure Estimates

EQUIPMENT	MTBF (hours)
Telescope Optics and Structure	10,000
Detector Translator	1,200
Image Intensifier/Converter Camera	750
Curved Crystal Spectrometer	1,000
Proportional Counter Spectrometer	2,500
H-alpha Slit Camera	3,000
Electronics Unit	5,000

4. NOTES

4.1 Bibliography - This report contains information obtained from the following documents. The documents are not referred to in the text.

a. Reference Earth Orbital Research and Applications Investigations (Blue Book), Volume II, Astronomy. January 15, 1971.

b. Design and Performance Specification, ATM Experiment S054, American Science and Engineering. 11 Carleton Street, Cambridge, Massachusetts. October 1, 1967.

c. Technical Proposal for a High Resolution X-Ray Spectroheliograph for the Second Solar ATM; a collaborative experimental program for coordinated high angular and spectral resolution observations of solar X-ray Phenomena, prepared by American Science and Engineering (Cambridge, Mass.), the University of Leicester (Leicester, England), and the Massachusetts Institute of Technology (Cambridge, Mass.).

d. Scientific Objectives and Instrument Performance Criteria for a Large Solar Observatory, The Aerospace Corporation, El Segundo, California, May 1972.

4.2 Abbreviations

Å	angstroms
ASMDS	Astronomy Sortie Missions Definition Study
ATM	Apollo Telescope Mount
Atm	atmospheric
cm	centimeter
C&D	Controls and Displays
cu ft	cubic foot
ENG	English units
I.I.	Image Intensifier
g	gravity acceleration unit
H.V.	High Voltage
H-α	Hydrogen Alpha
Inc.	Incidence
Ind	Indicator
kbps	Kilobits per second
K	degree Kelvin
max	maximum
m	meter
mJ/kg	milli-Joules per kilogram
nm	namometer
P.C.	Proportional Counter
PHA	Pulse Height Analyzer
PM	Photomultiplier
P.M.	Photomultiplier
Pos	Position
rad	radian
RF	radio frequency
S.C.	Slit Camera
sec	second
$\widehat{sec}$	arc-second
SI	International System of Units
sr	steradian
TBD	To be determined
TBS	To be supplied
Tel.	Telescope
W	watts
μrad	microradian
λ	wavelength

2.4 CORONAGRAPH ASSEMBLY (COR)

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

BASELINE EXPERIMENT DEFINITION DOCUMENT (BEDD)
ASMDS INNER AND OUTER CORONAGRAPHS

PREPARED BY:

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R. Shedko

APPROVED BY:

MARTIN MARIETTA CORPORATION
Denver Division
Denver, Colorado

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FIGURE

CONTENTS (Concluded)

1. INTRODUCTION

The purpose of this document is to define a baseline Coronagraph Telescope for the Astronomy Sortie Mission Definition Study.

The scientific objectives, configurations, operational requirements, environmental requirements, data, pointing, and controls and display requirements, estimated ground support equipment and post mission refurbishment requirements are identified.

2. DISCUSSION

2.1 Scientific Objectives - The Coronagraph Telescope assembly provides a continuous observation of the solar corona from one to thirty (1 to 30) solar radii. Coronal monitoring will allow the detection of outward-moving disturbances along the coronal streams and will aid in determining the phase velocities and quantities of matter involved.

2.2 Instrument Description - The instrument group for measurement of corona phenomena consists of:

a. 1 to 6 Solar Radii Coronagraph (Inner Coronagraph - IC)
b. 5 to 30 Solar Radii Coronagraph (Outer Coronagraph - OC)

These solar-disk-centered instruments are mounted together in a rigid assembly which is kept pointed at the center of the solar disk by platform gimballing. Figure 1 shows a typical arrangement of the Coronagraph instruments in one rigid assembly. The 1-to 6-solar-radii coronagraph combines with the 5-to 30-solar-radii coronagraph to observe white-light emission of outward-moving plasma clouds from the solar limb to a distance of 30 solar radii from the center of the sun. Coverage of this region is divided into two instruments for the following reasons: (1) the two instruments are each relatively small in size as contrasted with one instrument of unwieldy proportions; (2) the inner coronagraph, which requires a much smaller field of view, provides higher resolution for a given image size in the region where the coronal phenomena are expected to be more interesting; (3) the range-of-response requirement for the recording devices is considerably relaxed by splitting into two parts the six-to-eight-order-of-magnitude difference in radiation flux levels between the solar limb and 30 solar radii. Table I presents performance characteristics for both coronagraphs.

The combination of the two coronagraphs permits simultaneous recording of both inner and outer coronas. It permits each part of the corona to be recorded at an appropriate scale factor, thus taking advantage of a larger effective format to show the inner corona in more detail. If the coronagraph assembly is assigned to a supporting vehicle or platform that directs other instruments toward a particular spot on the sun, the coronagraph assembly will be mounted on limited gimabls, or flexure mounts, that allow the assembly optical axes to be solar-disk centered.

The 1-to 6-solar-radii coronagraph utilizes a film camera with a telephoto lens to restrict the field of view to 0.057 radians (3.25°) on a 18-mm format. It is fitted out with internal and external occulting disks to block out the direct rays of the sun so that the

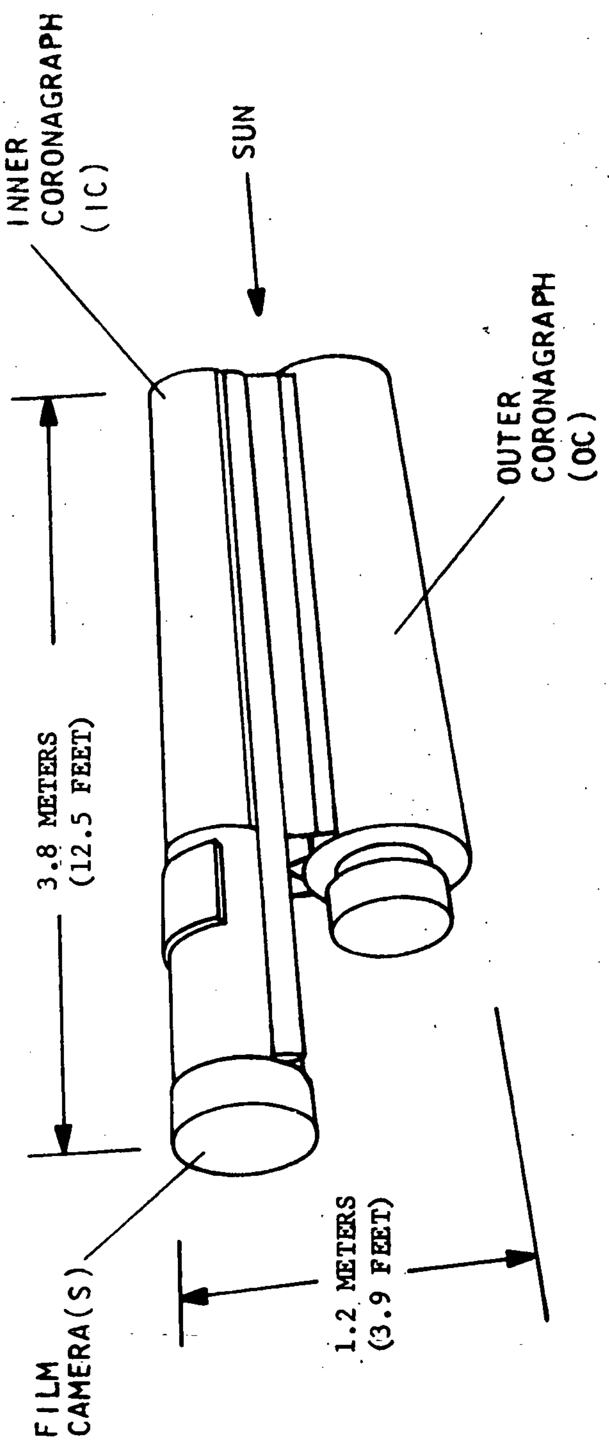


FIGURE 1 - INNER AND OUTER CORONAGRAPH ASSEMBLY

o SPECTRAL COVERAGE	400 TO 700 NANOMETERS (4000 TO 7000Å)
o F/NUMBER	F/12.9 - IC F/2.25 - OC
o FIELD OF VIEW	0.057 RADIANS (3.25°) - IC 0.26 RADIANS (15°) - OC
o FORMAT	18 MILLIMETERS (MM) - IC 24 MILLIMETERS (MM) - OC
o SCALE	31.7×10^{-4} RADIANS/MM (10.9 ARC-MINUTES/MM) - IC 1.11×10^{-2} RADIANS/MM (38 ARC-MINUTES/MM) - OC
o ANGULAR RESOLUTION	68×10^{-6} RADIANS (14 ARC-SECONDS) - IC 97×10^{-6} RADIANS (20 ARC-SECONDS) - OC

TABLE I - PERFORMANCE CHARACTERISTICS OF THE CORONAGRAPH ASSEMBLY

picture obtained contains the image of the inner corona without the glare of the direct sun. It is composed of four parts: an optical bench, which ties everything together; an optics housing, which provides a support for the objective lens, field lens, relay lens, folding mirrors, elements of the calibration chain, and thermal mirrors; a light tube which serves as a baffle, a support for the instrument cover, and protection for the external occulting disks; and a film camera which records the corona images.

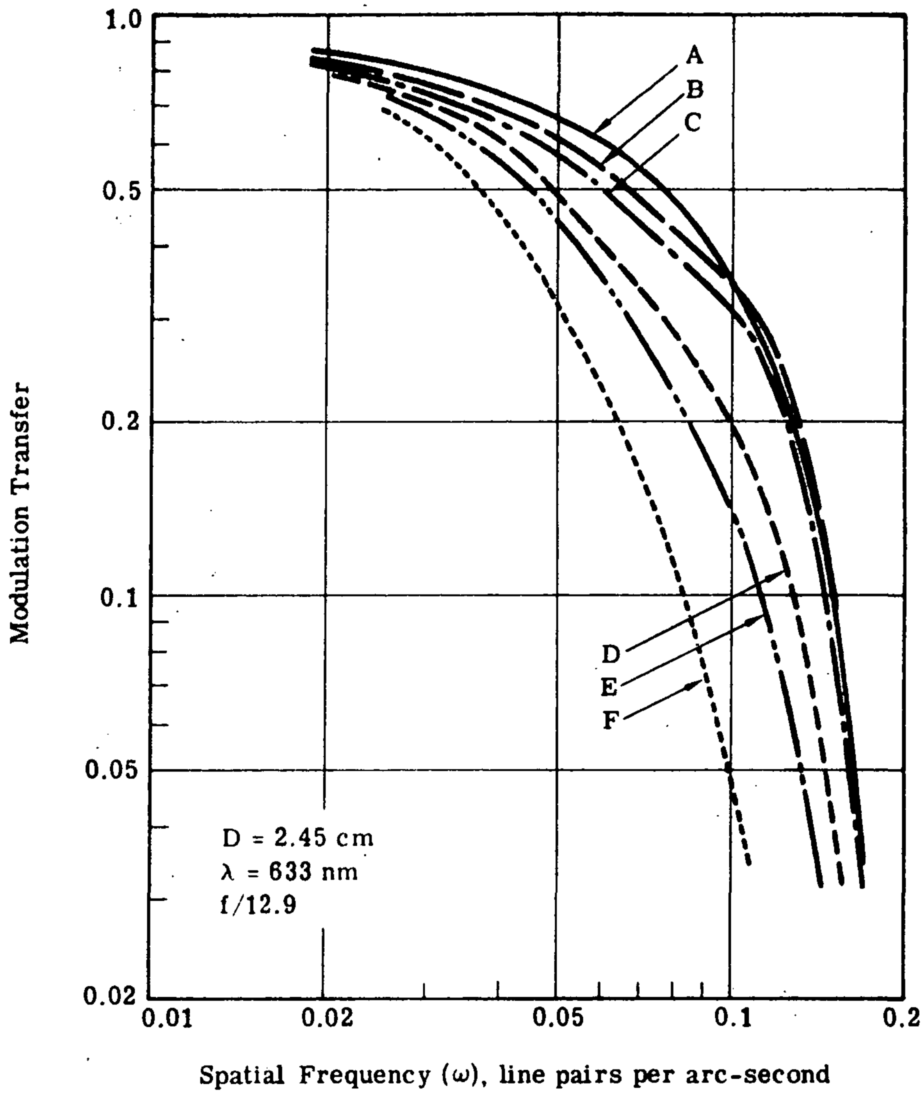
The 5-to 30-solar-radii coronagraph consists of a modification of the inner coronagraph design for observation of the outer corona. If the diameter of the light tube is increased, the objective lens will have an unobscured view out to a full field of 0.26 radians (15^o) or a view of the corona from 5 to 30 solar radii. An external occulting disk was sized to provide full occultation of the inner corona to 3 solar radii and no vignetting beyond 5 radii. The length of the light tube is identical to the 1- to 6 solar-radii coronagraph and the effective focal length of the optics was adjusted to provide a 24-mm format. The image registration device consists of a film camera.

The optics include an objective lens, a field lens with an occulting disk, and a relay lens pair. The external occulter is placed about 2.16 meters in front of the objective lens, with the additional occulting disks placed at strategic points in between.

The Blue Book calls for coronagraph spectral coverage from 400 to 1000 nm, requiring ir film. Since current ir films have moderate to low resolving power it seems that performance would have to be sacrificed to cover this range. For this reason a 400 to 700 nm coverage has been specified. This seems to be scientifically acceptable. The 15 arc-second pointing accuracy called for by the Blue Book has been reduced to 2 arc-seconds. This allows the corona to be seen to within 5 arc-seconds of the solar limb, which is a scientific objective.

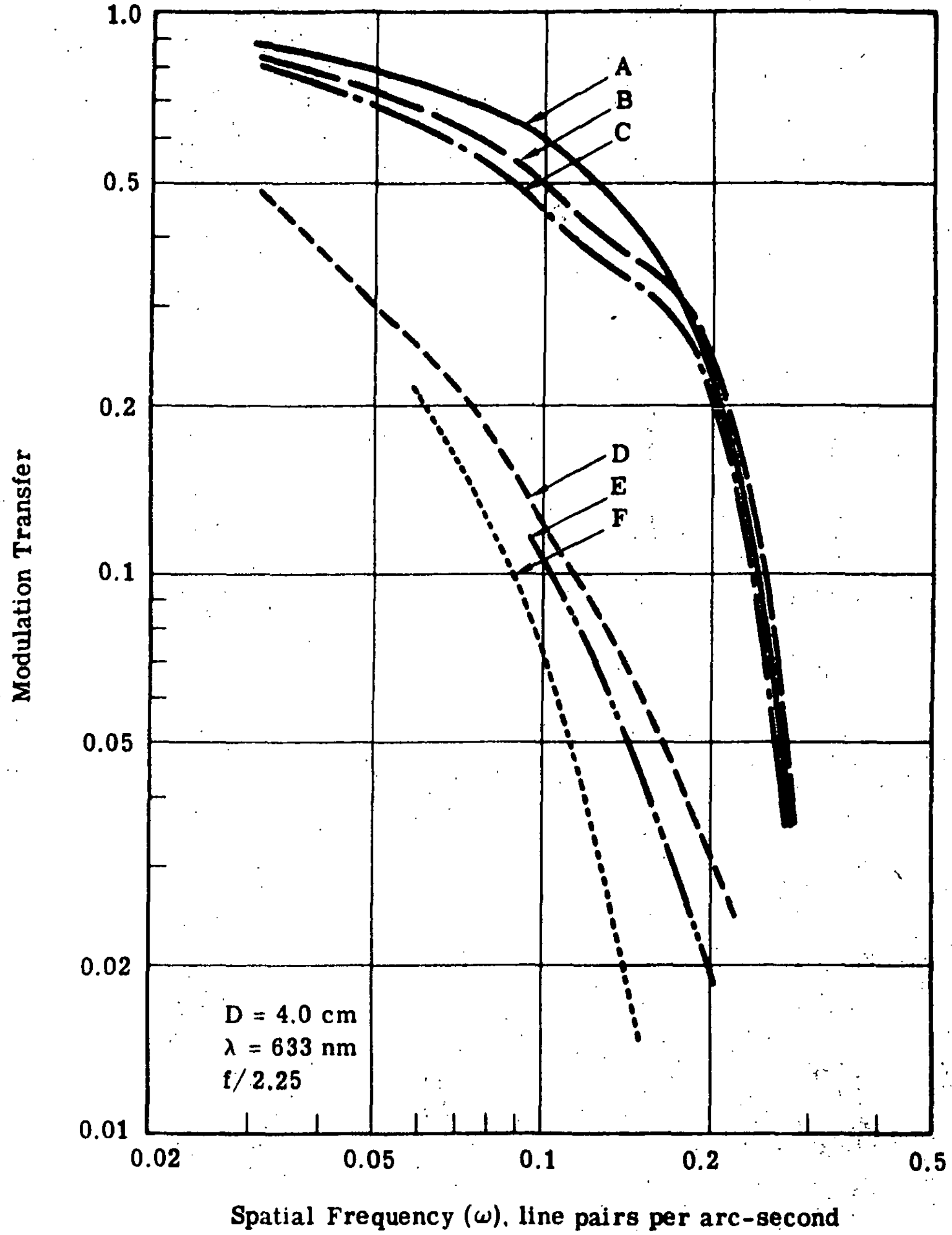
The MTF analysis of figure 2 for the inner coronagraph shows that pointing errors larger than 4.9×10^{-6} rad (1 arc-second) compromise performance. The figure shows that the Blue Book resolution requirement of 10 arc-seconds (0.1 line pairs/arc-second) can barely be met with the existing system. A 2 arc-second pointing error for instance, could make it impossible. A coronal contrast below 2:1 would raise the film AIM curve and again make 0.1 line pairs/arc-second unachievable. However, an angular resolution of 68×10^{6} radians (14 arc-seconds) does appear possible. The 0.057 radian (3.25^o) field of view is contained in an 18mm format. A larger format would consume more film and require longer exposures, but would also make the 10 arc-second resolution easier to achieve. The 10.9 arc-minute/millimeter scale differs from the Blue Book 11.5 arc-minute/mm value since the latter is inconsistent with other optical parameters.

The f/2.25 system for the outer coronagraph differs from the Blue Book f/12.9 since the f/12.9 number is inconsistent with such other requirements as focal length, plate scale and format. The MTF analysis for the outer Coronagraph in figure 3 shows that even 2 arc-seconds pointing error produces little degradation. However, the two coronagraphs are treated as an assembly and the inner-coronagraph requires 1 arc-second performance. The large field of view for the outer coronagraph results in a tight stability specification



A ———— Perfect optics
B — — 18% obscuration × curve A
C — - — 0.05λ rms WFE × curve B
D - - - - High resolution film × curve C
E — -- — 1.3-arc-sec rms image motion × curve D
F ------ 2.6-arc-sec rms image motion × curve B

FIGURE 2 - MTF ANALYSIS OF INNER CORONAGRAPH (IC)



A Perfect optics
B 26% obscuration × curve A
C 0.05λ rms WFE × curve B
D High resolution film × curve C
E 0.8-arc-sec rms image motion × curve D
F 1.6-arc-sec rms image motion × curve D

FIGURE 3 - MTF ANALYSIS OF OUTER CORONAGRAPH (OC)

on roll about the line of sight.

$$\rho = (2e/3\theta) \times (10^6/4.85)$$

where: ρ = required roll stability, (arc-seconds)

e = total pointing error; budget e/3 to roll error, (arc-seconds)

θ = total field of view, (arc-seconds)

Since we can tolerate e = 2 arc-seconds, and have $\theta \approx 15^{\circ} = 5.4 \times 10^4$ arc-seconds, we find ρ = 5 arc-seconds. The Blue Book specified 30 arc-seconds (0.033 line pairs/arc-second) resolution, which can easily be achieved with the baseline conditions. Rather than relax the optical system it is preferable to provide the astronomer with better performance. The MTF curve shows 97.0×10^{-6} radians (20 arc-seconds) as an achievable goal.

To provide symmetrical coronal coverage a 24 X 24 mm format is required. The Blue Book calls for a scale of 45 arc-minutes/mm. This is inconsistent with system f/number and focal length. Thirty-eight (38) arc-minutes/mm has been specified.

2.3 Instrument Interfaces and Characteristics

2.3.1 Equipment Interface Diagram - The equipment interface diagram is shown in figure 4. This diagram identifies the major interfaces between the coronagraph assembly and the spacecraft subsystems.

2.3.2 Scientific Equipment Characteristics - Preliminary scientific equipment characteristics are listed in table II.

2.3.3 Instrument Mounting and Alignment Requirements - Both coronagraphs are mounted on a common track (optical bench) which can be suspended within a gimbal ring. A sun sensor keeps the assembly centered on the solar image. If the coronagraph assembly is accommodated on a vehicle or platform that directs other (solar) instruments toward a particular spot on the sun, the coronagraph assembly will be mounted on limited gimbals, or flexure mounts that allow the assembly optical axes to be solar-disk centered.

The optics of each coronagraph are independent sealed units requiring no on-orbit adjustment. However, the positions of the external occulting disks are adjusted in orbit to obtain maximum suppression of diffraction effects. Use of a common optical bench assures the boresight alignment of the two coronagraph optics systems to each other. Actual alignment of the instrument (through the gimbals and pallet systems) must be lined up with the spacecraft reference axes within (TBD) radians. The true reference direction offsets between the instrument and the spacecraft axes must be known to (TBD) radians before launch.

2.4 Operations

2.4.1 Functional Flow Diagram - A gross outline of the functions required is shown in the Functional Flow Diagram of figure 5.

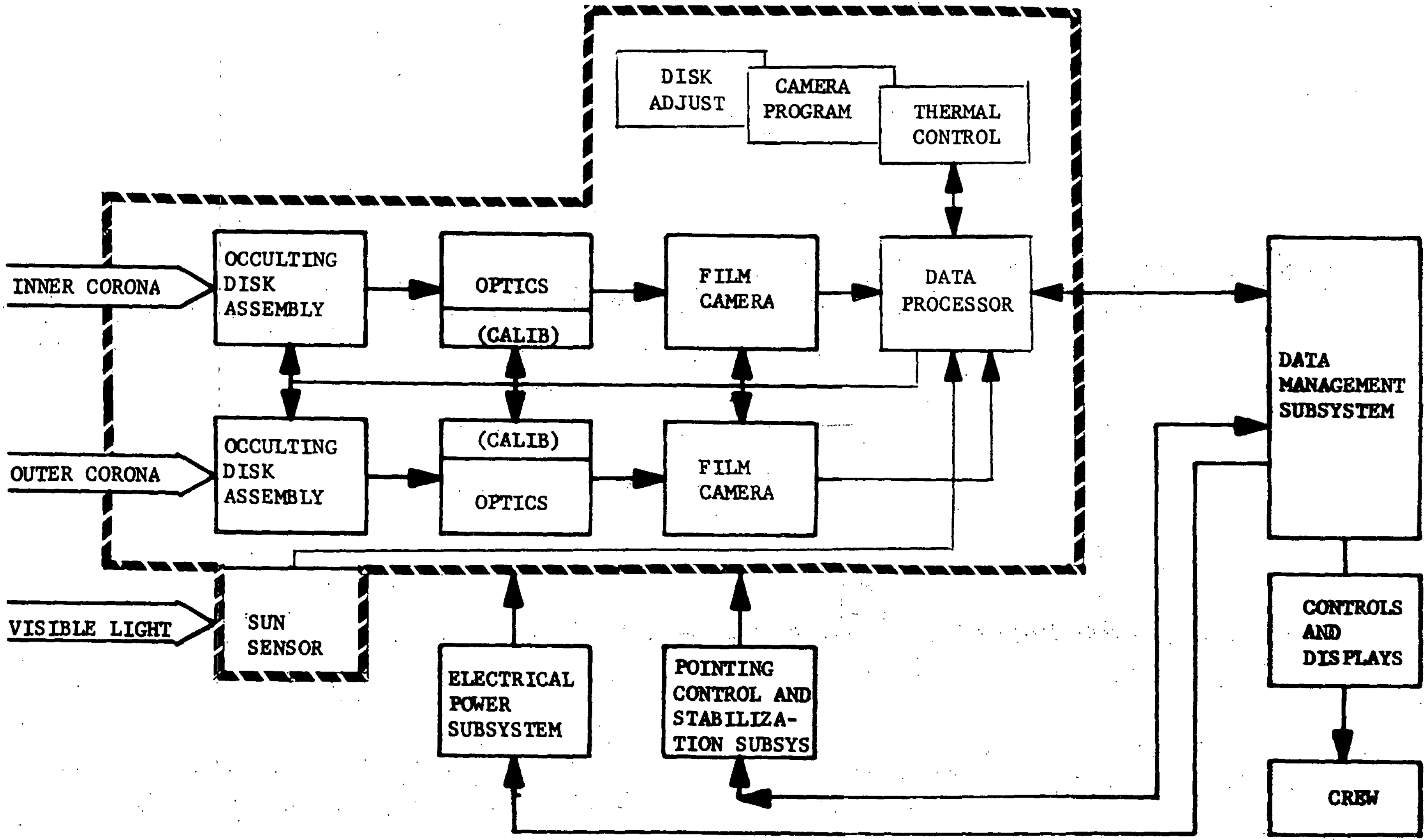


FIGURE 4 CORONAGRAPH ASSEMBLY INTERFACE DIAGRAM

		DIMENSIONS						
DESCRIPTION	QTY	WIDTH, M (IN)	HEIGHT, M (IN)	LENGTH, M (IN)	DIAMETER, M (IN)	VOLUME M^3 (FT^3)	WEIGHT KG (LBS)	POWER, WATTS
CORONAGRAPH ASSEMBLY	1	0.7	1.2	3.8	--		430 (945)	40 AVERAGE 60 PEAK
FINE SUN SENSOR (SUPPORT EQUIPMENT)	1						24.5 (54)	11
FILM CAMERA	2						15 (33)	8 (DURING 5 SECOND CYCLE CHANGE)
CORONAGRAPH, INNER	1					--	400 (881)	
CORONAGRAPH, OUTER	1					--		

TABLE II EQUIPMENT CHARACTERISTICS

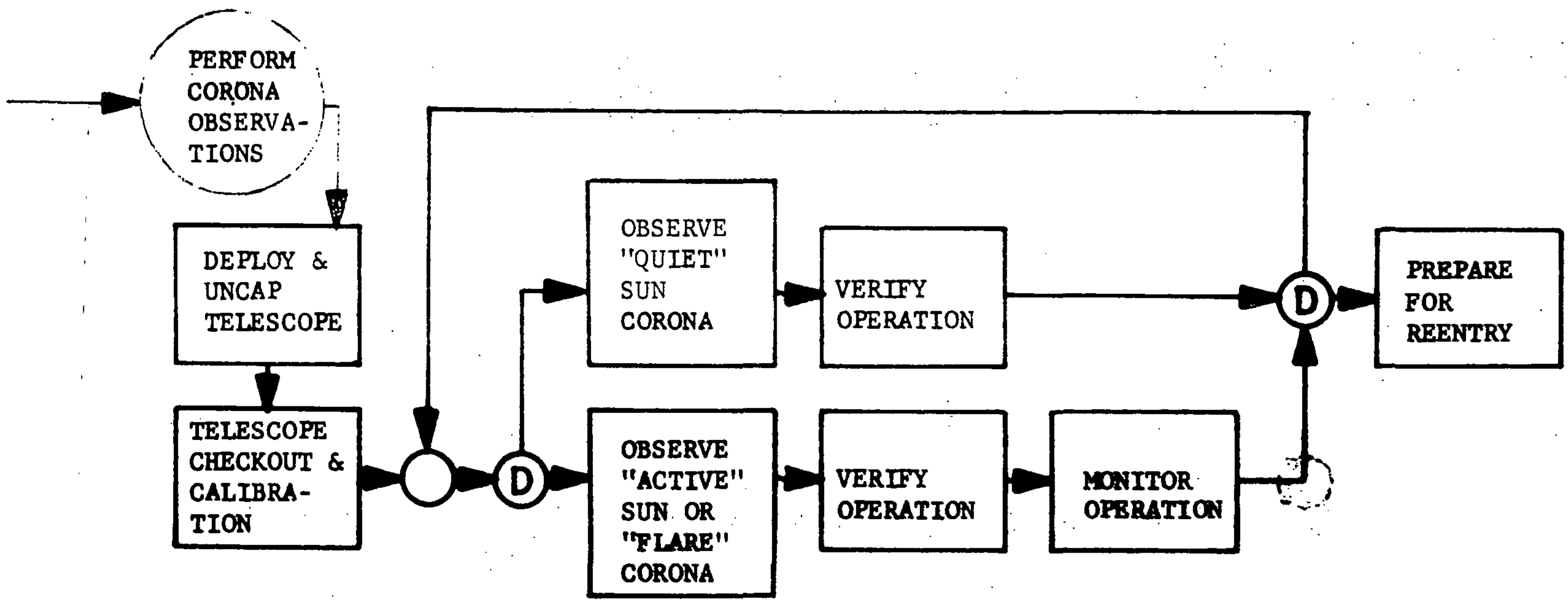


FIGURE 5 FUNCTIONAL FLOW DIAGRAM, SOLAR CORONAGRAPHS

2.4.2 Instrument Preparation Requirements - After the Shuttle has achieved stable orbit, and before any functions are performed with the instrument, a safety check of the instrument and support equipment is required, covers and lens caps are removed and a sun sensor is erected prior to release of the equipment for operation. The (hinged) deployment boom mechanism is erected and locked. Positions of the external occulting disks are adjusted to obtain maximum suppression of diffraction effects. Calibration of the systems is performed using intensity calibration wedges. Intensity-test images will be taken during operation depending on the frequency of photographs and the type of phenomena being observed.

2.4.3 Instrument Operation Requirements - The coronagraphs will operate continually while the sun can be observed. There will be an average of one exposure every three minutes. During normal operation (e.g. - quiet sun mode), the instrument will operate automatically and the crew will be required to monitor the operation infrequently. In the event of a flare occuring at or near the solar limb, the rate of operation will be increased with the crew controlling the experiment or commanding frequent data taking to correspond to the solar activity.

2.4.4 Instrument Post-Operation Requirements - The major post-operation functions are:

a. Turn off instrument power
b. Place instrument in the caged gimbal orientation
c. Retract the instrument into the shuttle
d. Reset the launch restraints
e. Turn off support equipment power and prepare instrument for reentry

These operations are performed by the crew through the controls and displays console.

2.4.5 Typical Instrument Operation Timelines - The experiment operational characteristics described in the above paragraphs are summarized in table III.

2.5 Environment - The environmental requirements and constraints associated with this instrument are listed in table IV.

2.6 Data - The scientific and engineering data generated is shown in table V.

2.7 Pointing

2.7.1 Accuracy - The 72.7×10^{-6} radians (15 arc-seconds) pointing accuracy specified in the Blue Book is reduced to 9.7×10^{-6} radians (2 arc-seconds) to allow the inner corona to be viewed to within 24.2×10^{-6} radians (5 arc-seconds) of the solar limb.

2.7.2 Stability - Pointing stability is specified at 4.9×10^{-6} radians (1 arc-second) and is established by performance requirements for the inner coronagraph.

OPERATING SEQUENCE / SUPPORT REQUIREMENTS	INITIAL							REPEATED (5/DAY)					FINAL				
	SAFETY CHECK	INITIAL POWER UP	RELEASE LAUNCH LOCKS AND DEPLOY COVERS & LENS CAPS	OPEN COVERS AND LENS CAPS	ACQUIRE SUN, ALIGN AND ADJUST OCCULTING DISCS	CALIBRATE INNER CORONAGRAPH	CALIBRATE OUTER CORONAGRAPH	OBSERVE SOLAR CORONA QUIET SUN	VERIFY OPERATION	OBSERVE SOLAR CORONA ACTIVE SUN OR FLARE	VERIFY OPERATION	MONITOR DATA ACQUISITION	CLOSE LENS CAPS & COVERS	RETRACT TELESCOPE & SECURE LAUNCH LOCKS	POWER DOWN ELECTRONICS	SUBSYSTEM POWER OFF	(PREPARE FOR REENTRY)
TIME MINUTES	2-20	45	34	11	48	12	10	260-1060	6	1060-260	6	12	26	10	6	2	-
CREW PARTICIPATION	X	X	X	X	X	X	X		X		X	X	X	X	X	X	
CORONAGRAPH ASSEMBLY	X	X	X					X		X				X	X	X	
INNER CORONAGRAPH				X	X	X			X		X		X				
OUTER CORONAGRAPH				X	X		X		X		X		X				
FILM CAMERAS					X	X	X		X		X	X					
(CONTROL AND DISPLAYS)		X	X	X	X	X	X		X		X	X	X	X	X	X	
(GIMBALLED MOUNT)	X	X	X		X			X		X				X		X	
POWER PROFILE (WATTS) INSTRUMENT		40 ———						(60-PEAK, FILM CHANGE)							——— 40		
DATA PROFILE (BPS)	-	10	10	110	110	110	110	110	110	110	110	110	110	10	-	-	

TABLE III EXPERIMENT OPERATIONAL CHARACTERISTICS

	OPERATING	NON-OPERATING
MECHANICAL		
o Vibration	Vibration loads must not cause deflections within the instrument greater than TBD microradians.	With launch locks set, stands launch and reentry loads.
o Acceleration	g-loads must not cause deflection within the instrument greater than TBD microradians (Less than 10^{-3}g)	With launch locks set, stands launch and reentry loads
o Acoustics	N/A	TBD
THERMAL	291°K to 297°K; 1 $^{\circ}$K Maximum temperature difference	263°K to 313°K
ATMOSPHERIC		
o Humidity	Less than 50%	Less than 50%
o Pressure	0 to 10^{5} N/m^{2} (0 to 15 psi)	0 to 10^{5} N/m^{2} (0 to 15 psi)
o Contamination	Slight sensitivity	(Telescope covered)

TABLE IV ENVIRONMENTAL REQUIREMENTS AND CONSTRAINTS

CLASS	DESCRIPTION	FORMAT	READOUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION	COMMENTS
SCIENTIFIC								
INNER CORONA	FILM STRIP, 35 MM	18 MM	ONE FRAME/ THREE MINUTES		AVERAGE		N/R	
OUTER CORONA	FILM STRIP, 35 MM	24 MM	ONE FRAME/ THREE MINUTES		AVERAGE		N/R	
							--	
ENGINEERING	EXPERIMENT EQUIPMENT	DIGITAL	CONTINU- OUS	100 BPS	100%		N/R	
	SUPPORT EQUIPMENT	DIGITAL	CONTINU- OUS	10 BPS	100%		N/R	

TABLE V CORONAGRAPH ASSEMBLY DATA REQUIREMENTS

2.8 Controls and Displays - The functional requirements for the controls and displays required to operate the instrument are listed in table VI.

2.9 Preflight/Postflight Ground Support - The major ground facility and equipment requirements are listed in table VII.

2.10 Post-Mission Refurbishment - The instrument will require refurbishment of the film cameras and the normal calibration and alignment sequences before flight.

2.11 Orbital Parameters - Continuous sun viewing for six days is desired for the coronagraph assembly. The minimum altitude for any inclination is that required for continuous sun viewing with an Earth atmosphere of 100 nautical miles.

3. PROGRAMMATICS

3.1 Equipment Cost and Schedule - Schedule and cost estimates for the solar coronagraphs are listed in Tables VIII and IX.

3.2 Safety Considerations - There are no pyrotechnic or explosive devices required for this telescope. The film magazines will be capable of containing sufficient film for the seven day sortie mission to preclude extravehicular activity.

3.3 Reliability - Equipment reliability will depend on the level of effort devoted to reliability during design, development, fabrication and test phases of the equipment.

4. NOTES

4.1 Bibliography - This BEDD contains information from the following documents. No reference to the documents is made in the text.

a. Reference Earth Orbital Research and Applications Investigations (Blue Book), Volume II - Astronomy, January 15, 1971.

b. Orbital Astronomy Support Facility (OASF) Study, NAS8-2103, McDonnell Douglas Corporation, Huntington Beach, California, 28 June 1968.

FUNCTION	COMPONENT	
	CONTROL	DISPLAY
OUTER CORONAGRAPH		
Main Power	Toggle Switch	Switch Position
Aperture Door	Toggle Switch	Status Light
Mode Select	Rotary Switch	Switch Position
Frames Remaining	--	5-Digit Counter
Data Status	Toggle Switch	--
Thermal Control	Toggle Switch	Switch Position
Mirror Position	Toggle Switch	Switch Position
Occulting Disc Position	Toggle Switch, 4 Position	Cross Pointer
Occulting Disc Alignment	Toggle Switch	Switch Position
INNER CORONAGRAPH		
Main Power	Toggle Switch	Switch Position
Aperture Door	Toggle Switch	Status Light
Mode Select	Rotary Switch	Switch Position
Frames Remaining	--	5-Digit Counter
Data Status	Toggle Switch	--
Thermal Control	Toggle Switch	Switch Position
Mirror Position	Toggle Switch	Switch Position
Occulting Disc Position	Toggle Switch, 4 Position	Cross Pointer
Occulting Disc Alignment	Toggle Switch	Switch Position

TABLE VI - PRELIMINARY FUNCTIONS AND CONTROL AND DISPLAY COMPONENTS FOR THE CORONAGRAPH ASSEMBLY

	Before Flight	During Flight	After Flight
1. Functions	1. Transportation 2. Receiving 3. Inspection 4. Handling 5. Storage 6. Installation and Assembly 7. Test and checkout 8. Alignment and Servicing 9. Interface Verification	1. Coordinate with Astronaut/Astronomer to change observing schedule	1. Post-Flight Checkout 2. Equipment Refurbishment 3. Data Distribution
2. Equipment	1. Shipping Container Including Environment Control 2. Handling Fixtures 3. Test and Checkout Equipment 4. Alignment Fixtures and Tooling (optical lab) 5. Clean Room, Class 100,000		Same as Preflight
3. Other	1. Ground Support Procedures 2. Dry Nitrogen Purge		

TABLE VII GROUND SUPPORT REQUIREMENTS

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)		(0.12)	(0.24)	(0.24)	(0.18)			$ 0.78
PRODUCTION-FIRST ARTICLE			(0.03)	(0.20)	(0.20)	(0.10)		0.53
								$ 1.31

TABLE VIII - SCHEDULE AND COST ESTIMATES, INNER (1 TO 6 SOLAR RADII) CORONAGRAPH

YEAR (QUARTER)	-6 (1 2 3 4)	-5 (1 2 3 4)	-4 (1 2 3 4)	-3 (1 2 3 4)	-2 (1 2 3 4)	-1 (1 2 3 4)	0 (1 2 3 4)	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)		(0.40)	(0.70)	(0.70)	(0.40)			$ 2.20
PRODUCTION-FIRST ARTICLE			(0.12)	(0.40)	(0.50)	(0.40)		1.42
								$ 3.62

TABLE IX - SCHEDULE AND COST ESTIMATES, OUTER (5 TO 30 SOLAR RADII) CORONAGRAPH

2.5 STRATOSCOPE III (SIII)

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

BASELINE EXPERIMENT DEFINITION DOCUMENT (BEDD)

STRATOSCOPE III (S III)

PREPARED BY:

R. Shedko

APPROVED BY:

MARTIN MARIETTA CORPORATION
Denver Division
Denver, Colorado

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FIGURE

TABLE

CONTENTS (Concluded)

1. INTRODUCTION

The purpose of this document is to define a baseline Stratoscope III (S III) Telescope for the Astronomy Sortie Mission Definition Study. The scientific objectives, configurations, operational requirements, environmental requirements, data pointing, and controls and display requirements, estimated ground support equipment and post mission refurbishment requirements are identified.

2. DISCUSSION

2.1 Scientific Objectives - The Stratoscope III allows the detailed observation of stellar objects in the 90 to 2000 nanometer (900 to 20,000 Å) spectral range.

2.2 Instrument Description - The SSIII is the successor to the balloon-borne stratoscope instrument and the predecessor to the 3-meter Large Space Telescope (LST). An outline of Stratoscope III is shown in Figure 1. The optical system is modeled from the LST with an F /2.2 primary mirror and an F /12 system. Scientific instrumentation provides the slitless spectrophotography of specific features in large emission nebulae for the UV (1000 to 3000 Å) and IR (5000 to 20,000 Å) spectral ranges. Field cameras are used to directly photograph the stellar galaxies in the ultraviolet and visible spectrum. Several camera fields are possible along with choices of spectrographs and polarimeters. One or two detectors will be preselected for each payload mission. LST type detectors are modified to use film as the primary method for data recording. Table I lists the performance characteristics and instrument detectors for the telescope.

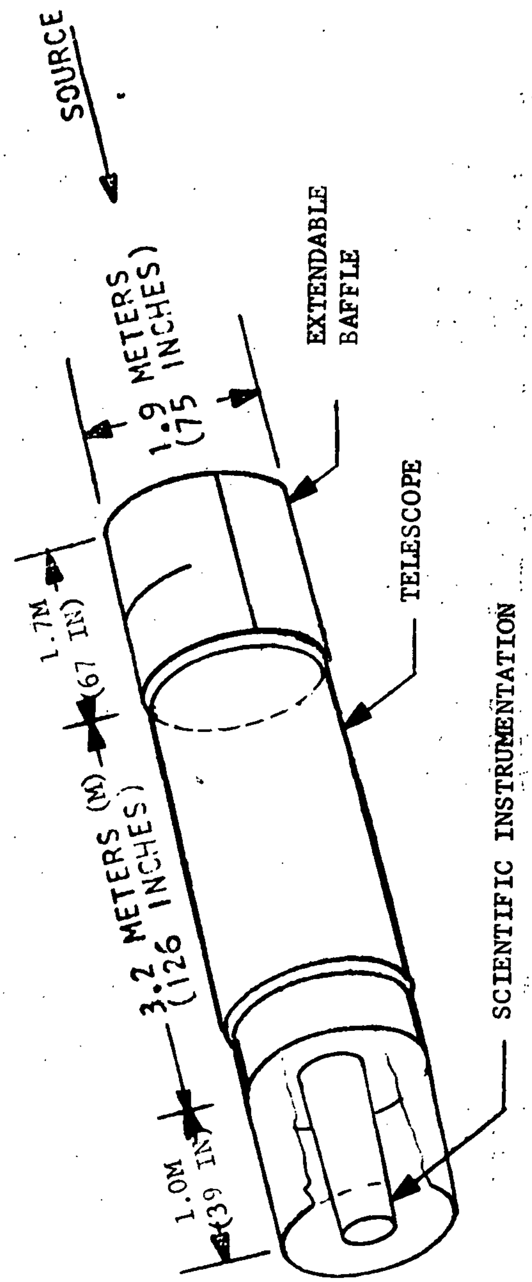


FIGURE 1 - STRATOSCOPE III DIMENSIONAL OUTLINE

o SPECTRAL COVERAGE	90 TO 2000 NANOMETERS (900 TO 20000Å)
	FIELD CAMERAS (1150 TO 6500Å)
	UV SPECTROGRAPHS (1000 TO 3000Å)
	IR SPECTROGRAPHS (5000 TO 20000Å)
	POLARIMETERS (900 TO 4000Å)
	ASPECT SENSOR (FIELD VIEWING)
o F/NUMBER	F/2.2 PRIMARY: F/12 OVERALL
o FIELD OF VIEW	17.5×10^{-4} RADIANS (6.0 ARC-MINUTES) @ F/24
o FORMAT	50 MILLIMETERS (MM)
o SCALE	67.9×10^{-6} RADIANS/MM (14 ARC-SECONDS/MM)
o ANGULAR RESOLUTION	1.45×10^{-6} RADIANS (0.3 ARC-SECONDS)

TABLE I - PERFORMANCE CHARACTERISTICS OF STRATOSCOPE III

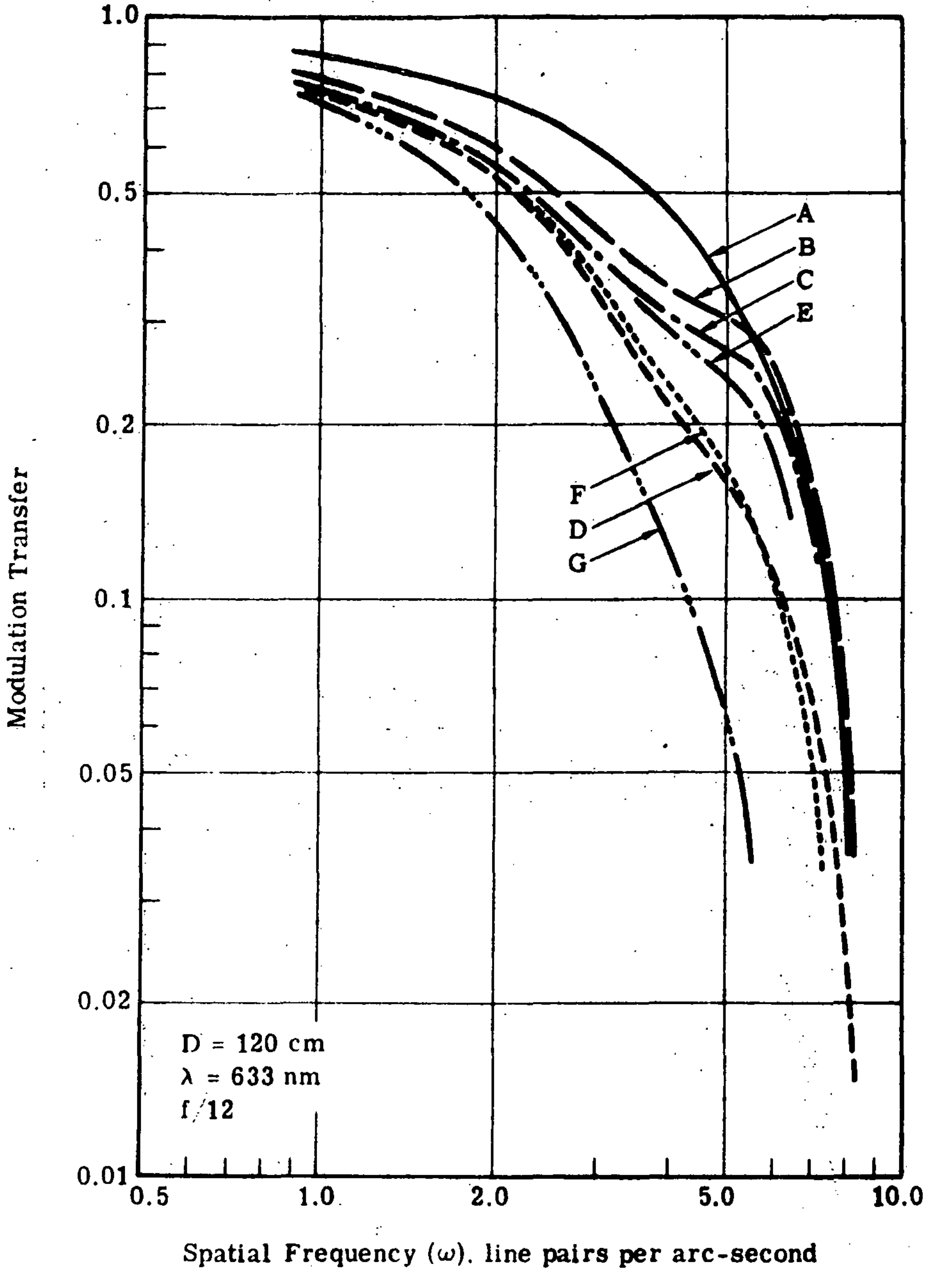
Stratoscope III is composed of three functional elements - an extendable baffle, the optical telescope assembly and the scientific instrumentation package. The extendable baffle contributes 0.2-meter to the overall diameter of SSIII and increases the overall length by 1.7 meters during operation. Conceivably, the shuttle could be flown to make the baffle unnecessary but only with restricted performance during the sortie mission. The optical telescope assembly (OTA) includes the optics, the forward structure, internal baffles, and systems for stabilization, thermal control, telescope alignment and focus. The telescope is a 120-cm aperture Ritchey-Chretian Cassegrain two-mirror system. The primary mirror focal ratio is f/2.2 with an overall telescope focal ratio of f/12. The scientific instrumentation package (SIP) converts the energy from the focal plane of the OTA into scientific information.

The perfrect MTF curve in Figure 2 has been degraded by the LST obscuration value of 34 percent. The LST wavefront error of 0.05 λ rms has been used. The large degradation caused by the film shows that a relay is required to achieve the resolution inherent in the telescope image. The relay converts the f/12 telescope to an f/24 telescope. An image stability requirement of 0.02 arc sec rms is required for the Stratoscope III.

2.3 Instrument Interfaces and Characteristics

2.3.1 Equipment Interface Diagram - The equipment interface diagram is shown in Figure 3. This diagram identifies the major interfaces between the Stratoscope III telescope and the support subsystems.

2.3.2 Scientific Equipment Characteristics - Preliminary scientific equipment characteristics are listed in Table II.



A	————————	Perfect optics
B	——— ———	34% obscuration × curve A
C	——— - ———	0.05λ rms WFE × curve B
D	— — — — —	High resolution film × curve C
E	——— -- ———	Same as curve D but at f/24
F	············	0.026-arc-sec rms image motion × curve E
G	——— ··· ———	0.053-arc-sec rms image motion × curve E

FIGURE 2 - MTF ANALYSIS OF STRATOSCOPE III (SIII)

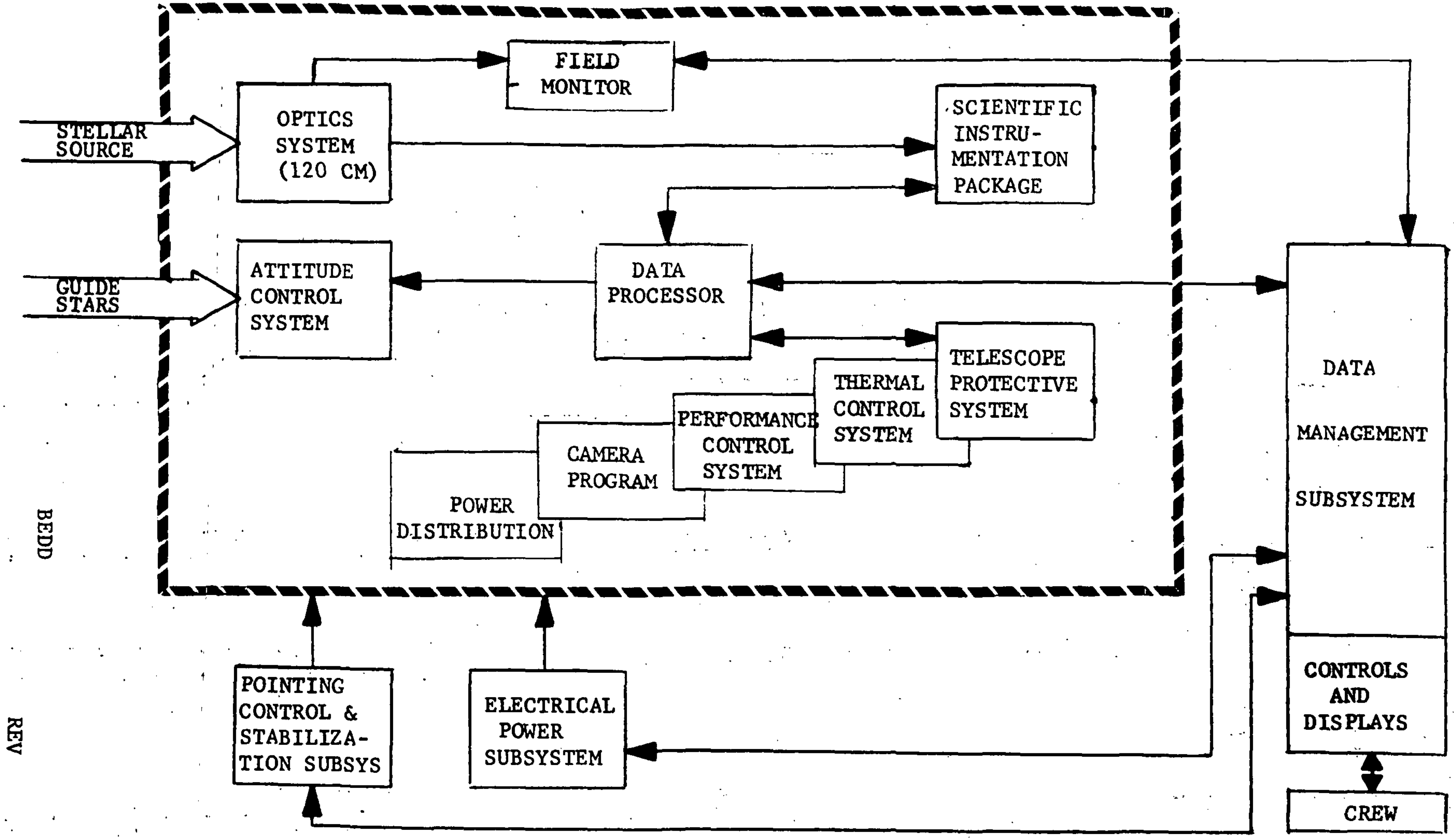


FIGURE 3 - STRATOSCOPE III INTERFACE DIAGRAM

DESCRIPTION	QTY	DIMENSIONS					WEIGHT KG (LBS)	POWER, WATTS
		WIDTH, M (IN)	HEIGHT, M (IN)	LENGTH, M (IN)	DIAMETER M (IN)	VOLUME M^3 (FT^3)		
STRATOSCOPE III (SIII)	1			4.2 166	1.9 (75)	11.92 (420)	1800 (3961)	140 AVERAGE 180 PEAK
SIII - BAFFLE EXTENDED	1			5.9 (232)	1.9 (75)		1800 (3961)	140 AVERAGE 180 PEAK
TELESCOPE	1						1100 (2420)	
SCIENTIFIC INSTEUMENTS							700 (1541)	

TABLE II EQUIPMENT CHARACTERISTICS

2.3.3 Instrument Mounting and Alignment Requirements - The complete telescope assembly is suspended within a gimbal ring. The supporting vehicle must allow a half-angle field of view of 16.9×10^{-4} Radians (5.8 arc minutes) for the telescope. A moveable cover will be provided for the telescope viewing aperture which can be closed during launch and non-operational periods in orbit. Actual alignment of Stratoscope III (through the gimbals and pallet systems) must be lined up with the spacecraft reference axes within (TBD) radians. The true reference direction offsets between the instrument and the spacecraft axes must be known to (TBD) radians before launch.

2.4 Operations

2.4.1 Functional Flow Diagram - A gross outline of the operational functions for the Stratoscope III telescope is shown in the Functional Flow Diagram of Figure 4.

2.4.2 Instrument Preparation Requirements - After the supporting vehicle has achieved stable orbit and before any functions are performed with the telescope, a safety check of the Stratoscope III and support equipment is performed. Covers and lens caps are removed prior to release of the equipment for operation. The (hinged) deployment boom mechanism is erected and locked. Electronic and control circuits are energized and the film system will expose a series of photographs of various standard sources. Calibrations will be performed at intervals driving operation depending on the amount of photographs taken and the type of phenomena being observed.

2.4.3 Instrument Operation Requirements - Stratoscope III is limited to viewing no closer than 45 degrees to the Sun and 15 degrees to the Earth

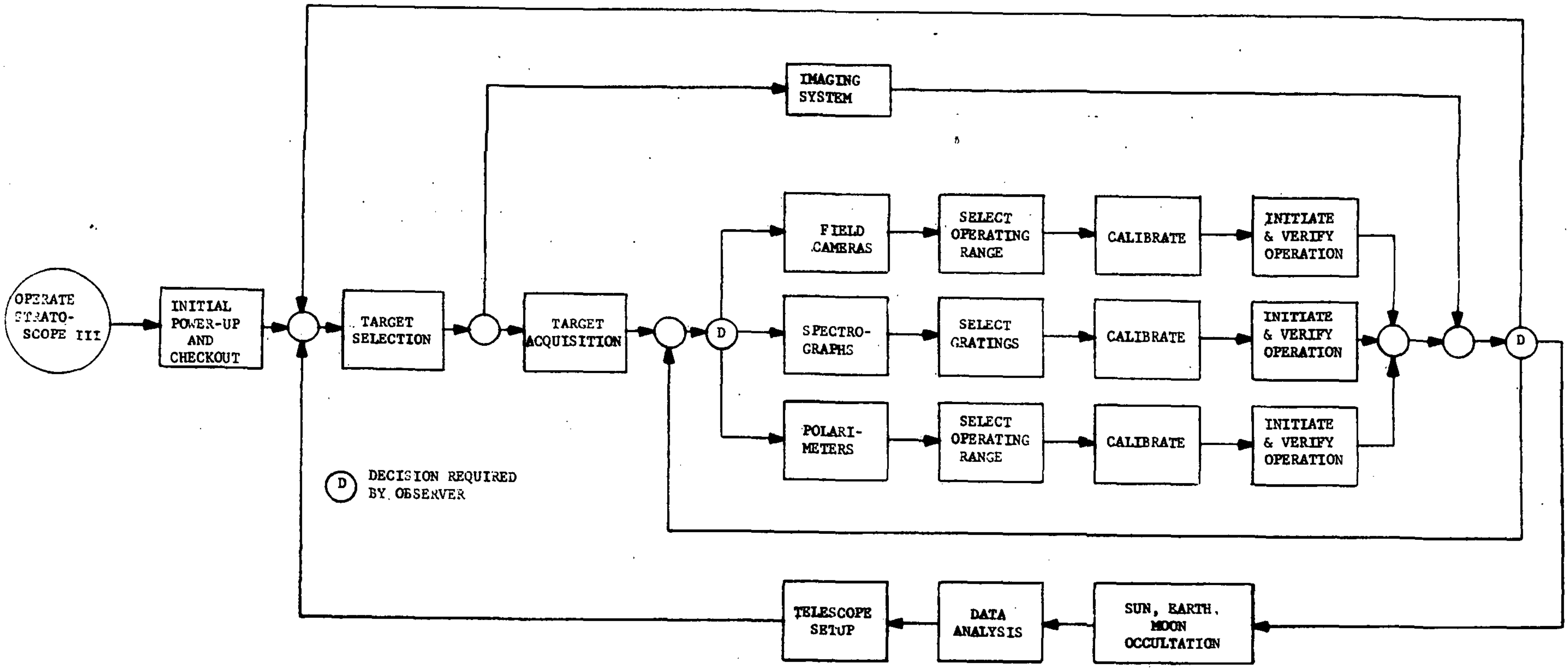


FIGURE 4 - STRATOSCOPE III TELESCOPE FUNCTIONAL FLOW DIAGRAM

and Moon. As a result of this constraint, targets are continuously viewable in 15% of the celestial sphere, other targets are viewable from at least 50 minutes per orbit to 94 minutes per orbit in 60% of the celestial sphere, and no targets are viewable in 15% of the celestial sphere which is continuously occulted by the sun. For an operations altitude of 463 kilometers (250 n. mi.) and an inclination of 0.497 Radians (28.5 degrees), an observation duration of 70 minutes is developed from the repeatable on-orbit operations sequence.

2.4.4 Instrument Post-Operation Requirements - Major post-operation functions are:

a. Turn off instrument detector power

b. Place instrument in the caged gimbal orientation

c. Retract the instrument into the shuttle

d. Reset the launch restraints

e. Turn off support equipment power (except for re-entry monitoring instrumentation).

These operations are performed by the crew through the controls and displays console.

2.4.5 Typical Instrument Operation Timelines - The experiment operational characteristics described in the above paragraphs are summarized in Table III.

2.5 Environment - The environmental requirements and constraints associated with this instrument are listed in Table IV.

2.6 Data - The scientific and engineering data generated is shown in Table V.

OPERATING SEQUENCE / SUPPORT REQUIREMENTS	INITIAL						REPEATED						FINAL			
	SAFETY CHECK	INITIAL POWER UP	RELEASE LAUNCH LOCKS AND DEPLOY	OPEN COVERS, EXTEND SHIELDS	FUNCTIONAL CHECK & TEMPERATURE STABILIZATION	ALIGN & CALIBRATE	ACQUIRE TARGET	SELECT FILTER OR GRATING	CALIBRATE	OBSERVE TARGET	VERIFY & MONITOR OPERATION	SELECT DETECTOR	CLOSE LENS CAP AND COVER, RETRACT SHIELD	RETRACT TELESCOPE AND SECURE LAUNCH LOCKS	POWER DOWN ELECTRONICS	SUBSYSTEM POWER OFF
TIME MINUTES	10	1	36	12	44	34	12	1	7	70	-	1	20	56	4	2
CREW PARTICIPATION	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
STRATOSCOPE III	X	X	X	X	X	X							X	X	X	X
INSTRUMENTS						X	X	X	X	X	X	X				
(CONTROL & DISPLAYS)		X	X	X	X	X	X	X	X		X	X	X	X	X	X
(GIMBALLED MOUNT)	X	X	X		X	X	X	X		X				X		X
POWER PROFILE (WATTS) INSTRUMENT		180 ←			→ 180	140	140 ←					→ 140	140 ←		→ 140	
DATA PROFILE (BPS)		2200 ←												→ 2200		

TABLE III STRATOSCOPE III OPERATIONAL CHARACTERISTICS

	OPERATING	NON-OPERATING
MECHANICAL		
o Vibration	Vibration loads must not cause deflections within the instrument greater than TBD microradians.	With launch locks set, stands launch and reentry loads.
o Acceleration	g-loads must not cause deflection within the instrument greater than TBD microradians (less than 10^{-4}g).	With launch locks set, stands launch and reentry loads
o Accoustics	N/A	TBD
THERMAL	$291^{o}K$ to $297^{o}K$;	$253^{o}K$ to $309^{o}K$
ATMOSPHERIC		
o Humidity	Less than 40%	Less than 40%
o Pressure	0 to 10^5 N/m^2 (0 to 15 psi)	0 to 10^5 N/m^2 (0 to 15 psi)
o Contamination	Sensitive	(Telescope covered)

TABLE IV ENVIRONMENTAL REQUIREMENTS AND CONSTRAINTS

CLASS	DESCRIPTION	FORMAT	READOUT RATE	NOMIAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION	COMMENTS
SCIENTIFIC	FILM STRIP, 70 MM	50 MM	ONE FRAME PER MINUTE	--	80%	8000 FRAMES	N/R	
	FIELD MONITOR	DIGITAL (ANALOG)	(CONTINU-OUS)	$7X10^6$ BPS (11 MHZ)	100%			
ENGINEERING	EXPERIMENT EQUIPMENT	DIGITAL	CONTINU OUS	2000 BPS	100%	10^9 BITS	N/R	
	SUPPORT EQUIPMENT	DIGITAL	CONTINU-OUS	200 BPS	100%		N/R	

TABLE V STRATOSCOPE III DATA REQUIREMENTS

2.7 Pointing

2.7.1 Accuracy - The pointing accuracy requirement for the telescope is 9.7×10^{-6} Radians (2.0 arc-seconds). The scientific instrumentation pointing specification is determined by the small aperture of the spectrographs and polarimeters. (LST analysis shows that) the smallest aperture to be used will approximate the system resolution and the detector pointing requirement will be 1.47×10^{-6} Radians (0.3 arc-seconds).

2.7.2 Stability - Pointing stability for the telescope is specified at 0.49×10^{-6} Radians (0.1 arc-seconds). An internal, closed loop guiding system is required to provide image stability of 9.7×10^{-8} Radians (0.02 arc-seconds) to the instrument detectors.

2.8 Controls and Displays - The functional requirements for the controls and display required to operate the instrument are listed in Table VI.

2.9 Preflight/Postflight Ground Support - The major ground facility and equipment requirements are listed in Table VII.

2.10 Post-Mission Refurbishment - The instrument will require refurbishment of the film cameras and the normal calibration and alignment sequences before flight.

2.11 Orbital Parameters - The desired orbit inclination is 0.497 (28.5 degrees). The desired operations orbit altitude is 463 kilometers (250 n. mi.). The telescope is limited to viewing no closer than 45 degrees to the Sun and 15 degrees to the Earth and Moon.

3. PROGRAMMATICS

3.1 Equipment Cost and Schedule - Schedule and cost estimates for the Stratoscope III are given in Table VIII.

FUNCTION	CONTROL	DISPLAY
GENERAL		
Aperture Door	Toggle Switch	Status Light
Launch Locks	Toggle Switch	Switch Position
Thermal Control	Toggle Switch	Switch Position
Main Power	Toggle Switch	Switch Position
Instrument Select	Rotary Switch	Switch Position
Filter Wheel Position	Rotary Switch	Switch Position
Alignment Translate	Toggle Switch, (4 Position)	--
Alignment Rotate	Toggle Switch, (4 Position)	--
Alignment Status	--	Cross Pointer
Focus	Toggle Switch	--
Focus Status	--	Vertical Meter
Field Monitor High Voltage	Toggle Switch	Switch Position
Field Monitor	--	TV Monitor
FIELD CAMERA NO. 1		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Frames Remaining	--	5-Digit Counter
Exposure Duration	Rotary Switch	Switch Position
Mode Select	Rotary Switch	Switch Position
FIELD CAMERA NO. 2		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Frames Remaining	--	5-Digit Counter
Exposure Duration	Rotary Switch	Switch Position
Mode Select	Rotary Switch	Switch Position
FIELD CAMERA NO. 3		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Frames Remaining	--	5-Digit Counter
Exposure Duration	Rotary Switch	Switch Position
Mode Select	Rotary Switch	Switch Position
FIELD CAMERA NO. 4		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Frames Remaining	--	5-Digit Counter

TABLE VI - FUNCTIONAL REQUIREMENTS FOR STRATOSCOPE III CONTROLS AND DISPLAYS

TABLE VI (CONTD.)

FUNCTION	CONTROL	DISPLAY
Exposure Duration	Rotary Switch	Switch Position
Mode Select	Rotary Switch	Switch Position
IMAGING SPECTROGRAPH		
Power	Toggle Swtich	Switch Position
Data Status	Toggle Switch	Status Light
Frames Remaining	--	5-Digit Counter
Calibration	Toggle Switch	Status Light
Slit Select	Rotary Switch	Switch Position
Grating Mode Select	Rotary Switch	Switch Position
Exposure Duration	Rotary Switch	Switch Position
Grating Position	--	Digital (4)
HIGH SPEED SPECTROGRAPH		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Frames Remaining	--	5-Digit Counter
Calibration	Toggle Switch	Status Light
Exposure Duration	Rotary Switch	Switch Position
ECHELLE SPECTROGRAPH		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Frames Remaining	--	5-Digit Counter
Calibration	Toggle Switch	Status Light
Exposure Duration	Rotary Switch	Switch Position
LYMAN SPECTROMETER		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Mode Select	Rotary Switch	Switch Position
Calibration	Toggle Switch	Status Light
NEAR IR SPECTROGRAPH		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Mode Select	Rotary Switch	Switch Position
Calibration	Toggle Switch	Status Light

TABLE VI (CONTD.)

FUNCTION	CONTROL	DISPLAY
<u>MIDDLE IR SPECTROMETER</u>		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Calibration	Toggle Switch	Status Light
Mode Select	Rotary Switch	Switch Position
<u>WOLLASTON POLARIMETER</u>		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Calibration	Toggle Switch	Status Light
Mode Select	Rotary Switch	Switch Position
<u>REFLECTIVE POLARIMETER</u>		
Power	Toggle Switch	Switch Position
Data Status	Toggle Switch	Status Light
Calibration	Toggle Switch	Status Light
Mode Select	Rotary Switch	Switch Position

	Before Flight	During Flight	After Flight
1. Functions	1. Transportation 2. Receiving 3. Inspection 4. Handling 5. Storage 6. Installation and Assembly 7. Test and checkout 8. Alignment and Servicing 9. Interface Verification	1. Coordinate with Astronaut/Astronomer to change observing schedule	1. Post-Flight Checkout 2. Equipment Refurbishment 3. Data Distribution
2. Equipment	1. Shipping Container Including Environment Control 2. Handling Fixtures 3. Test and Checkout Equipment 4. Alignment Fixtures and Tooling (optical lab) 5. Clean Room, Class 100,000		Same as Preflight
3. Other	1. Ground Support Procedures 2. Dry Nitrogen Purge		

TABLE VII GROUND SUPPORT REQUIREMENTS

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)		(2.4)	(2.6)	(2.2)	(1.2)			$ 8.4
PRODUCTION-FIRST ARTICLE			(1.0)	(2.0)	(3.0)	(1.2)		7.2
								$ 15.6

TABLE VIII - SCHEDULE AND COST ESTIMATES, 120 CM STRATOSCOPE III

3.2 Safety Considerations - There are no pyrotechnic or explosive devices required for the Stratoscope III telescope. Film magazines for the various detectors will be capable of containing sufficient film for the seven day sortie mission to preclude extravehicular activity.

3.3 Reliability - Equipment reliability depends upon the level of effort devoted to reliability during design development, fabrication and test phases of the equipment. Failure mode analysis is limited to identifying single-point failures. Change control is provided at the End Item Specification level until the refurbishment phase, and then at the released engineering level.

4. NOTES

4.1 Bibliography - This BEDD contains information from the following documents. No reference to the documents is made in the text.

a. Reference Earth Orbital Research and Applications Investigations, (Blue Book), Volume II Astronomy, January 15, 1971.

b. Instrumentation Package for a Large Space Telescope, GSFC X-670-70-400, November 1970.

c. LST Definition Study (MSFC Phase A Concept of OTA), Itek 71-8209-1, December 15, 1971.

d. Preliminary Design for a Manned Astronomical Space Telescope (MAST), Kollsman Report, July 1969.

2.6 INFRARED TELESCOPE (IRT)

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

BASELINE EXPERIMENT DEFINITION DOCUMENT (BEDD)
ASMDS INFRARED TELESCOPE

Prepared by

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Approved by

MARTIN MARIETTA CORPORATION
DENVER DIVISION
DENVER, COLORADO

TABLE OF CONTENTS

1.0 INTRODUCTION

The purpose of this document is to define the experiment baseline for the Infrared (IR) Telescope which will be adopted for the Astronomy Sortie Missions Definition Study (ASMDS). The experiment objectives, configuration, physical interfaces, data, operational, environmental, pointing, control and displays, ground support, and refurbishment requirements are identified.

2.0 DISCUSSION

2.1 Scientific Objectives - The objective of the IR Telescope is to provide improved capabilities for detailed observation of cosmic, galactic, planetary and diffuse IR sources in the 0.7 to 1000 micrometer (um) spectral region at better sensitivities than possible from aircraft in the atmosphere or from ground-based sites. Observations and measurements of specific IR sources are needed to determine intensity and spectral characteristics for comparison or correlation with X-ray spectra for the same sources. The shape of the spectrum and characteristics of spectral lines will enable the determination of IR and X-ray emission mechanisms.

The objective of the radiometry experiment is to make observations of weak sources at selected spectral bandwidth. The radiometry experiment will utilize the detector array to enable long-term observation and measurements of selected IR sources. For each source, photometric brightness and variation measurements will be made versus a selected spectral bandwidth. The technical objective of high resolution spectrometry is the successive improvement in IR spectral coverage and resolution in space for low level inputs. The continuous spectrum from 0.7 um to 1000 um will be measured per source to obtain characteristics that would define IR emission mechanisms.

2.2 Instrument Description - The IR telescope must be cooled in its entirety to very low cryogenic (27.6°K) temperatures. The detectors in the IR telescope, at the focus of the optical path, must be kept at even lower cryogenic temperatures. To suppress "noise" in the detection and recording system, temperatures as low as 2°K are desired. These extremely low temperatures apply only to the detectors and objects in the detector field of view and not to the telescope as a whole. The basic optical parameters for the telescope are:

- Telescope Type: Cassegrain
- Free Aperture: 100 centimeters (cm)
- Focal Ratio: 10
- Obscuration of Aperture: 25%
- Wavelength (λ) Range: 0.7 to 1000 micrometers (um)
- Design Wavelength: 4 um
- Total Field of View: 14.5 X 10^{-4} radians (5 arc minutes)
- Wave Front Error (WFE): 0.10 λ rms
- Pointing Accuracy: 19.4 X 10^{-6} radians (4.0 arc seconds)
- Stability: 1.94 X 10^{-6} radians (0.4 arc seconds)
- Angular Resolution: 19.4 X 10^{-6} radians (4.0 arc seconds)
- Format: 15 millimeters (mm)
- Plate Scale: 1.02 X 10^{-4} radians/mm (21 arc seconds/mm)

The IR instrumentation section containing an interferometer and a detector array is mounted directly behind the primary mirror. The IR detector array is used for radiometry. An optical telescope, for simultaneous visible-light imaging, is mounted to the IR telescope outside the superinsulation. Additional instruments include the precision boresight tracker and the field viewing electronic imaging unit. The electronics are located so that the heat that is emitted will not affect the temperature of the IR telescope. Instruments within the super cold IR telescope housing are translated independently to the focal point. The telescope structure incorporates a liquid neon shield surrounding the cylindrical telescope walls. Layers of superinsulation are utilized outside the liquid neon shield as well as at the pivotable aperture cover. The IR telescope chill-down and sustained cooling equipment are included as part of the support

equipment. Liquid neon supply tanks will be packaged together with valves, venting devices, regulators, and temperature control equipment in a liquid neon supply assembly. Insulated receiving tanks combined in another assembly are used to collect gaseous neon during observation periods. The gaseous neon will be vented to space during non-observation periods. The detector array is uniformly cooled to $2^{O}K$ by a combination of peltier cooling and heat exchange with a liquid helium cryostat. The cryostat located in the telescope lowers the detector element temperature to $2^{O}K$.

The MTF analysis of figure 1 assumes 25 percent obscuration, for a fast primary miiror, moderate field, and good baffling. A 0.1 λ rms wavefront error at 4 micormeters is used in the analysis. The spatial frequency response of the infrared sensor is taken to be a (sin x)/x function. It was assumed that 0.1- X 0.1-millimeter elements would be used. The sensor focal length combination significantly affects system performance. Analysis of the system may show that a slower optical system would pay off in higher resolution even though the exposure may be longer. The decision depends on the wavelengths of interest since at 40 micrometers the sensor has relatively little effect on MTF. The four micrometer spectral region was chosen because, being near the most difficult end of the spectral range of the IRT, it would indicate what sort of limits on performance might occur. Figure 1 shows that an image stability of 1.94 X 10^{-6} radians (0.4 arc-second) is sufficient at 4 micrometers.

The experiments utilized for stellar observation will include alignment, calibration, guide star acquisition, and desired object location processes. The initial primary experiments are linear detector array radiometry, and high resolution spectrometry of previously located sources. In the radiometry experiment the telescope is pointed at the object of interest for long periods of time. An interferometer is incorporated in the instrumentation section of the telescope for high resolution

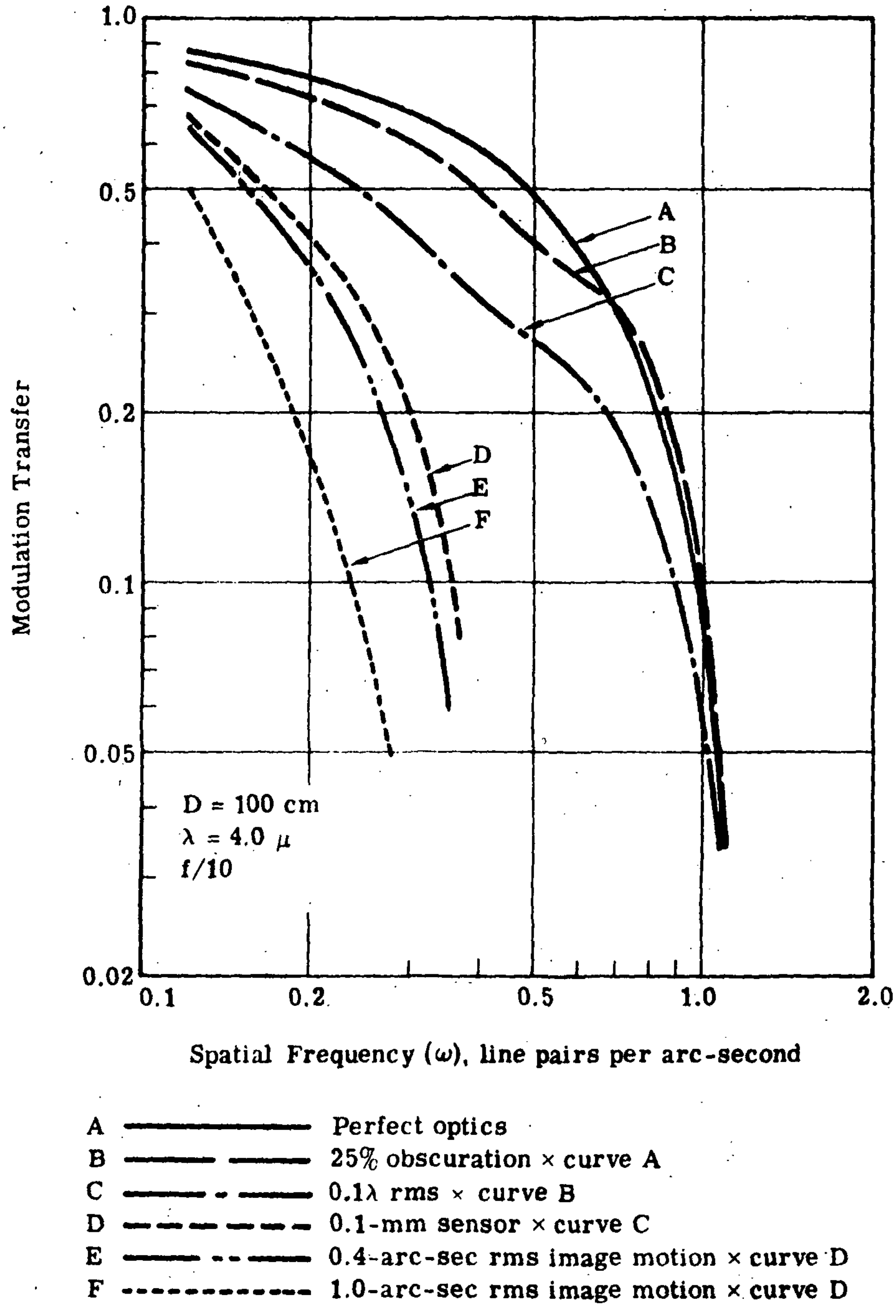

FIGURE 1 - MTF ANALYSIS OF INFRARED TELESCOPE (IRT)

spectrometry. The infrared energy collected by the telescope is passed through a hole in the unit where the interferometer is to be used. The optical arrangement of the interferometer divides the energy to create an interference pattern. A detector reads out the interference pattern as a function of time and the position of the movable mirror.

An outline sketch of the IR telescope is shown in Figure 2.

2.3 Instrument Interfaces and Characteristics

2.3.1 Equipment Interface Diagram - The interface diagram for the Infrared Telescope is shown in Figure 3. This diagram identifies the major interfaces between the instrument and support subsystems. The telescope is mounted on a gimbal to provide freedom to orient the viewing axis independently of the carrier vehicle's pointing constraints.

2.3.2 Equipment Characteristics - The scientific and support equipment required are shown in Table I. This table includes the instrument components required as well as some details concerning individual detector units.

2.4 Operations

2.4.1 Functional Flow Diagram - An experiment functional block diagram is shown in Figure 4. This diagram shows the various possible sequences of experiment operation.

2.4.2 Instrument Preparation Requirements - The telescope will be delivered into orbit prechilled with liquid neon (LNe) at $27.6^{\circ}K$. The instrumentation is tested after protective covers and supports are removed. Contaminant monitors and IR background sensors will be activated and must show acceptable levels before the telescope aperture cover is opened. Optical alignment is checked in the red portion of the visible spectrum and a number of artificial IR sources, supplemented by stars, are used to calibrate the equipment.

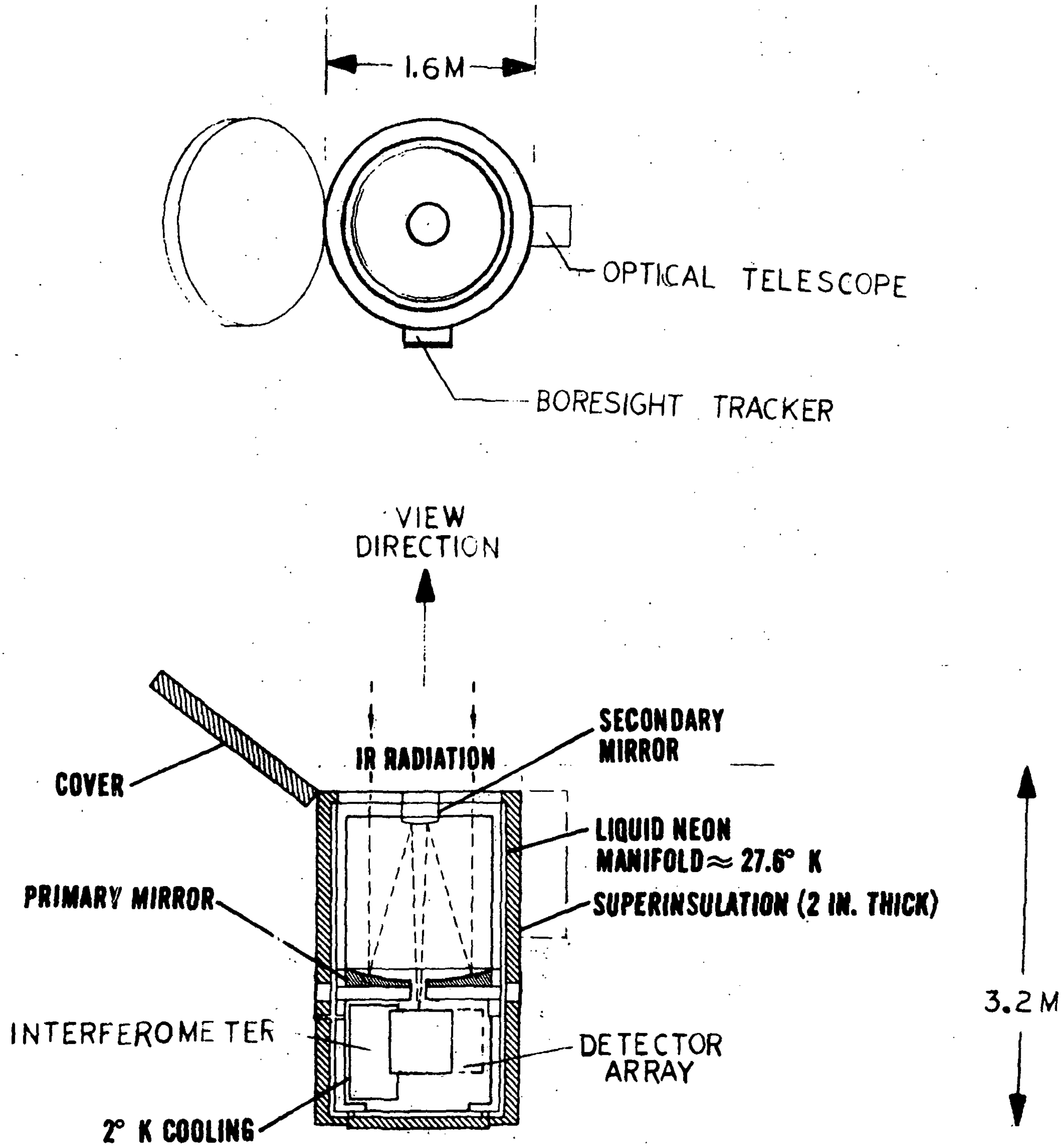

FIGURE 2 - INFRARED TELESCOPE DIMENSIONAL SKETCH

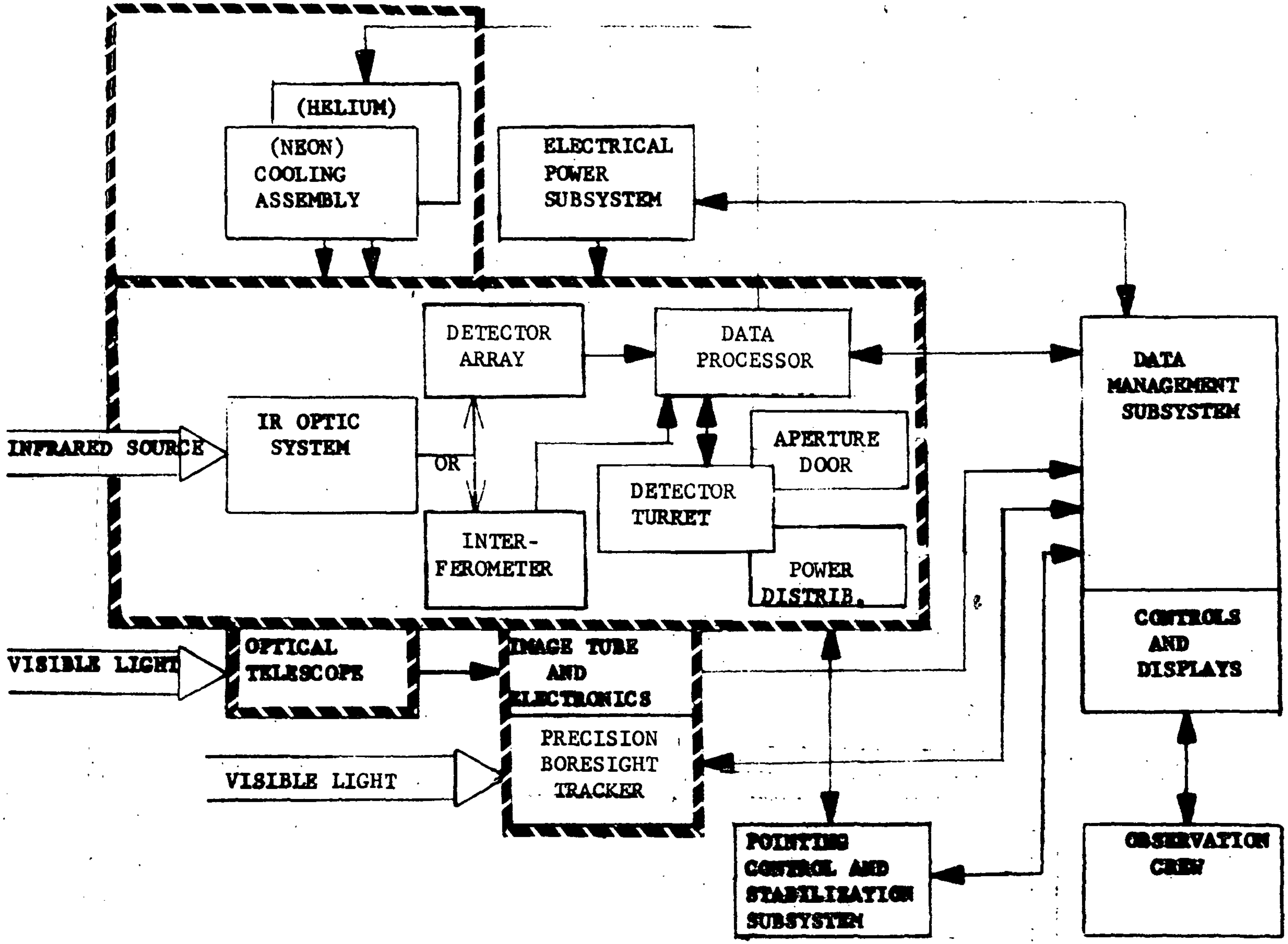

FIGURE 3 INFRARED TELESCOPE INTERFACE DIAGRAM

	DESCRIPTION	QTY	WIDTH, M (IN)	HEIGHT, M (IN)	LENGTH M (IN)	DIAMETER, M (IN)	VOLUME, M^3 (FT^3)	WEIGHT, KG (LBS)	DATA, Kbps	POWER, WATTS
EXPERIMENT EQUIPMENT	Infrared Telescope	1	-	--	3.2M (126 IN)	1.6 M (63 IN)	9.1M^3 (319 FT^3)	917 KG (2020LBS)	0.20	
	Detector Array (Radiometry)	1	-	-	0.34M (13.5 IN)	0.2M (8 IN)		42KG (93 LBS)	0.232	10W Ave
	Interferometer	1	-	-	0.46M (18 IN)	0.3M (13 IN)		59KG (131 LBS)	1.232	10W Ave
	Control Unit (Interferometer)	1	0.2M (8 IN)	0.1M (4 IN)	0.33M (13 IN)	-	.007M^3 (0.2 FT^3)	2.3 KG (5 LBS)	0.032	10W Ave 50W Peak (1 MIN)
SUPPORT EQUIPMENT	Cryogens: Neon Helium	-						400 KG (882 LBS) 10 KG (22 LBS)		
	Shield Cooling Assembly (Neon)	1	0.76M (30 IN)	0.6M (24 IN)	1.5M (59 IN)	-	0.687M^3 (24.2 FT^3)	47.6KG (105 LBS)	0.10	5W Ave 50W Peak
	Instrument Cooling Assembly (Helium)	1	1.5M (59 IN)	0.6M (24 IN)	2.1M (82 IN)	-	1.86M^3 (65.6 FT^3)	61.4KG (135 LBS)	0.10	
	Precision Bore-sighted Star Tracker	1	0.31M (12 IN)	0.31M (12 IN)	0.48M (19 IN)		--	11.3 KG (25 LBS)		10W
	Optical Tele-scope and Image Tube	1	0.15M (6 IN)	0.15M (6 IN)	0.94M (37 IN)		0.21M^3 (0.8 FT^3)	48 KG (106 LBS)	7X10^6 (11 MHz)	30W Ave

TABLE I SCIENTIFIC AND SUPPORT EQUIPMENT CHARACTERISTICS

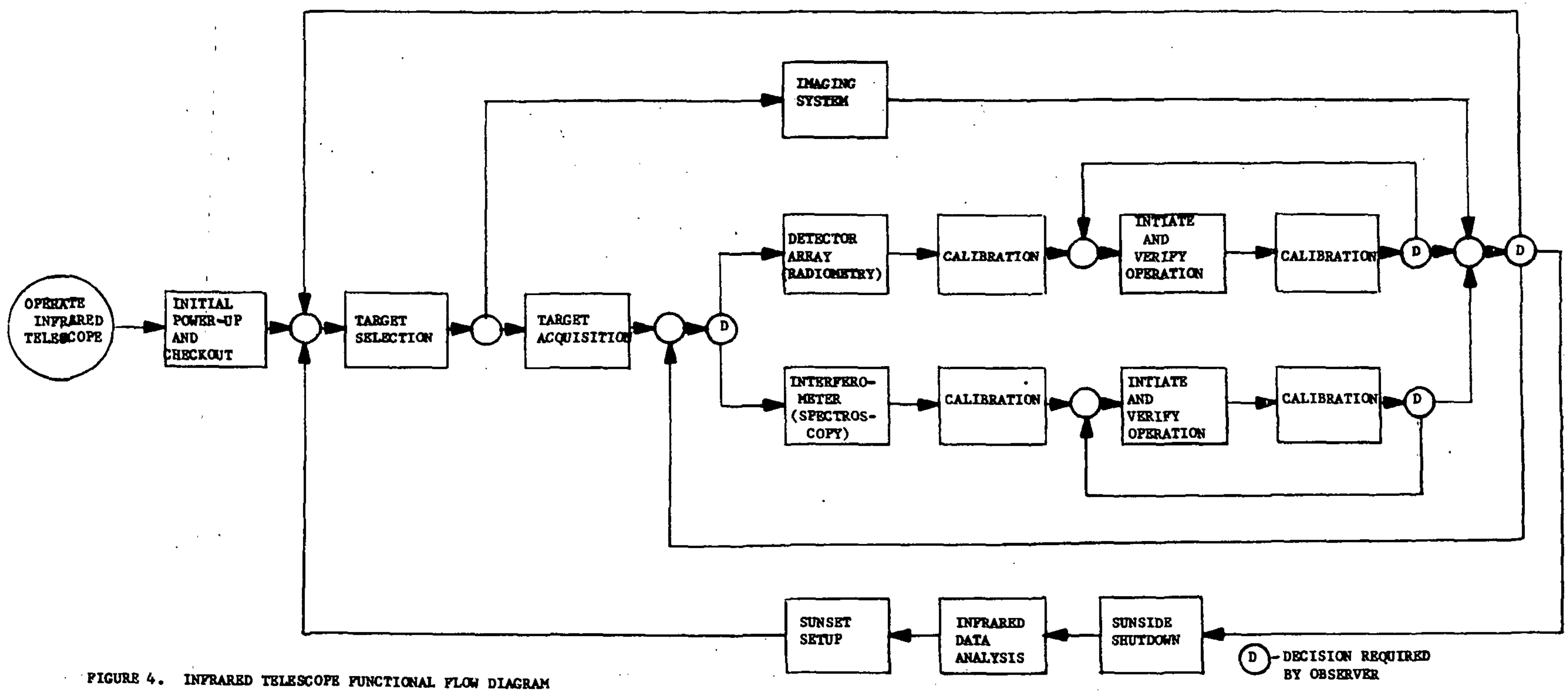

FIGURE 4. INFRARED TELESCOPE FUNCTIONAL FLOW DIAGRAM

2.4.3 Instrument Operation Requirements - Temperatures of the various parts of the instrument are monitored during observations. A calibration observation for the spectral region of interest is taken, then the actual observations for data, and then the calibration observations are repeated. This calibrate-read-calibrate procedure ensures that the true conditions under which the data were collected are known. The telescope aperture is usually closed when the telescope is pointing closer than 90^o to the center of the sun, 45^o to the center of the moon and closer than 45^o to the edge of the Earth to avoid excessive heat input and liquid neon and helium losses.

2.4.4 Instrument Post-Operation Requirements - The telescope must be positioned so that the launch locks can be re-activated. The instrumentation power circuits are placed in off condition (except for re-entry monitoring instrumentation).

2.4.5 Instrument Operation Timelines - A typical operational sequence and the estimated times involved are shown in Table II. Use of experiment and support equipment is indicated along with power, data and stability timelines.

2.5 Environment - The environmental requirements and constraints are listed in Table III.

2.6 Data - The scientific and engineering data generated is shown in Table IV.

2.7 Pointing

2.7.1 Accuracy - Desired pointing accuracy for the radiometry and high resolution spectroscopy experiments is 20×10^{-6} radians (4 arc-sec).

2.7.2 Stability - Desired pointing stability is 1.9×10^{-6} radians (0.4 arc-sec) over the observation period of 900 to 14,400 seconds.

EXPERIMENT OPERATING SEQUENCE / SUPPORT REQUIREMENTS	TIME (MINUTES)	CREW PARTICIPATION	INFRARED TELESCOPE	IMAGING SYSTEM	DETECTOR ARRAY	INTERFEROMETER	CONTROL UNIT		SHIELD COOLING ASSEMBLY	INSTRUMENT COOLING ASSEMBLY	(CONTROLS AND DISPLAYS)		(GIMBALLED MOUNT)		POWER PROFILE (WATTS) EXPERIMENT	POWER PROFILE (WATTS) SUPPORT	DATA PROFILE (BPS)		STABILITY	(1) EQUIPMENT IS TURNED ON, BUT NOT SPECIFICALLY USED FOR THIS OPERATION
SAFETY CHECK	2	X	X						X	X			X		10	← 5 WATTS AVERAGE, 50 WATTS PEAK →	200			
ELECTRICAL POWER ON	1	X	X				X		X	X	X		X		50		1360			
RELEASE LAUNCH LOCKS	20	X	X	X					(1)	(1)	X		X		30		200			
FUNCTIONAL CHECK AND TEMPERATURE STABILIZATION	5 HRS	X	X	X	X	X	X		X	X	X		X		50		2760			
ALIGN AND CALIBRATION SEQUENCE	60	X		X	X	X	X		(1)	(1)	X				50		2560			
ASPECT SENSING	5	X		X					(1)	(1)	X				30		200			
ACQUIRE GUIDE STAR	6	X		X							X		X		30		200			
TARGET SELECTION	5	X							(1)	(1)										
OPERATE IMAGING SYSTEM	9	X		X					(1)	(1)	X				30		200			
TARGET ACQUISITION	5	X		X					(1)	(1)	X				30		200			
OPERATE RADIOMETRY EXPERIMENT	30	X			X				(1)	(1)					10		1560			
START SUN SIDE STANDBY	1	X							(1)	(1)							1360			
ENTER SUNSIDE	--																1360			
INFRARED DATA ANALYSIS AND INTERPRETATION	28	X							(1)	(1)	X						[illegible]			
INDEX TO INTERFEROMETER	6	X							(1)	(1)	X						1360			
CHECKOUT AND CALIBRATE INTERFEROMETER	18	X				X	X		(1)	(1)	X				60		2560			
ACQUIRE GUIDE STAR	6	X		X					(1)	(1)	X				30		200			
TARGET SELECTION AND ACQUISITION	6	X		X					(1)	(1)	X				30		200			
OPERATE SPECTROSCOPY EXPERIMENT	30	X				X	X		(1)	(1)	X				20		2560			
START SUNSIDE STANDBY	1	X							(1)	(1)							1360			
ENTER SUNSIDE	--																1360			
INFRARED DATA ANALYSIS AND INTERPRETATION	28	X							(1)	(1)	X						1360			
	--																			
	--																			
SET TO LAUNCH ORIENTATION	10	X	X										X				1360			
SET LAUNCH LOCKS	15	X	X										X				200			
POWER OFF	1	X	X						X	X	X		X				200			

TABLE II TYPICAL OPERATIONAL TIMELINES

	OPERATING	NON-OPERATING
MECHANICAL		
o Vibration	Vibration loads must not cause deflections within the instrument greater than TBD microradians.	With launch locks set, stands launch and reentry loads.
o Acceleration	g-loads must not cause deflection within the instrument greater than TBD microradians	With launch locks set, stands launch and reentry loads
o Acoustics	N/A	TBD
THERMAL	$28^{\circ}K$ for telescope, 0.5 to $1^{\circ}K$ maximum temperature difference $2^{\circ}K$ for detectors	$263^{\circ}K$ to $303^{\circ}K$ Prechilled to $28^{\circ}K$; No cooling after mission observation mode.
ATMOSPHERIC		
o Humidity	N/A	Approximately zero percent
o Pressure	Detectors: 10^{-6} Torr Acceptable 10^{-7} Torr Preferred	0 to 15 psi
o Contamination	Severe problem if hot environmental leaks and H_2O dumps are present	(telescope covered)
EXTERNAL INTERFERENCES		
o Magnetic Fields	N/A	N/A
o RF Fields	Less than 10^{-16} Watts-Meter^{-2}	N/A
o Ionizing Background	N/A	N/A

TABLE III ENVIRONMENTAL REQUIREMENTS AND CONSTRAINTS

CLASS	DESCRIPTION	FORMAT	READOUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION	COMMENTS
SCIENTIFIC	DETECTOR ARRAY OUTPUT	DIGITAL	ONCE/ ORBIT	200 BPS	33%		N/R	
	INTERFERO- METER OUTPUT	DIGITAL	ONCE/ ORBIT	1200 BPS	33%		N/R	
	FIELD VIEWING TELESCOPE	DIGITAL (ANALOG)	(CONTINU- OUS FOR GUIDANCE)	$7X10^6$ BPS (11 MHZ)	100%		--	
ENGINEERING	EXPERIMENT EQUIPMENT	DIGITAL	CONTINU- OUS	1160 BPS	100%		N/R	
	SUPPORT EQUIPMENT	DIGITAL	CONTINU- OUS	200 BPS	100%		N/R	

TABLE IV INFRARED TELESCOPE DATA

2.7.3 Slew Rate - The desired maximum slew rate is 17.4 X 10^{-4} radians per second (360 arc sec per second). A maximum slew rate of 11.6 X 10^{-4} radians per second (240 arc sec per second) is acceptable.

2.8 Controls and Displays - Table V lists the functional requirements for the controls and displays required to perform the experiments.

2.9 Preflight and Postflight Ground Support - A cryogenics and optical laboratory capable of accepting the assembled IR telescope module and its accessories in both the room temperature and the 27.6^{O}K telescope and 2^{O}K instrument conditions is desired. Test and calibration sets are needed for each of the experiment instrument units. A typical ground based control center operating position together with communication links and information processing equipment will enable integrated checkout tests and operations simulations. The test, checkout and calibration functions and equipment are listed in Table VI.

2.10 Post Mission Refurbishment - The scientific equipment will require refurbishment of the two cryogenic systems to ready the experiment for reflight. Arrays and the interferometer must undergo the normal calibration sequences before reflight.

FUNCTION	COMPONENT	
	CONTROL	DISPLAY
<u>TELESCOPE</u>		
Main Power	Toggle Switch	Switch Position
Aperture Door	Toggle Switch	Status Light
Launch Lock System	Toggle Switch	Switch Position
Telescope Thermal Control	Toggle Switch	Status Light
Instrument Select	Toggle Switch	Switch Position
Focus	Toggle Switch	Vertical Meter
Alignment Translate	Toggle Switch, 4 Position	--
Alignment Rotate	Toggle Switch, 4 Position	--
Alignment Status	--	Cross Pointer
Field Monitor	--	TV Monitor
<u>RADIOMETER</u>		
Detector Gain	Rotary Switch	--
	Potentiometer	Vertical Meter
	Toggle Switch	Switch Position
Detector Bias	Rotary Switch	--
	Potentiometer	--
	Toggle Switch	Vertical Meter
Detector Temperature	Potentiometer	Vertical Meter
Detector Select	Toggle Switch	Switch Position
Mode Select	Rotary Switch	Switch Position
Cryogen Cooling	Toggle Switch	Status Light

TABLE V PRELIMINARY FUNCTIONS AND C&D COMPONENTS FOR IR TELESCOPE

FUNCTION	COMPONENT	
	CONTROL	DISPLAY
RADIOMETER (Cont'd)		
Calibration	Toggle Switch	Status Light
Data Status	Toggle Switch	Status Light
SPECTROMETER		
Thermal Control	Toggle Switch	Switch Position
Detector Gain	Toggle Switch	--
	Potentiometer	Vertical Meter
Detector Bias	Toggle Switch	--
	Potentiometer	Dual Scale Vertical Meter
Detector Temperature	Potentiometer	Dual Scale Vertical Meter
Detector Select	Toggle Switch	Switch Position
Scan Range	Rotary Switch	Switch Position
Scan Rate	Rotary Switch	Switch Position
Zero Offset	Potentiometer	Vertical Meter
Calibrate	Toggle Switch	Status Light
Data Status	Toggle Switch	Status Light

TABLE V PRELIMINARY FUNCTIONS AND C&D COMPONENTS FOR IR TELESCOPE (Cont'd)

	Before Flight	During Flight	After Flight
1. Functions	1. Transportation 2. Receiving 3. Inspection 4. Handling 5. Storage 6. Installation and Assembly 7. Test and checkout 8. Alignment and Servicing 9. Interface Verification	1. Coordinate with Astronaut/Astronomer to change observing schedule	1. Post-Flight Checkout 2. Equipment Refurbishment 3. Data Distribution
2. Equipment	1. Shipping Container Including Environment Control 2. Handling Fixtures 3. Test and Checkout Equipment 4. Alignment Fixtures and Tooling (optical lab) 5. Clean Room, Class 100,000 6. Chilldown Facilities		Same as Preflight
3. Other	1. Ground Support Procedures 2. Dry Nitrogen Purge 3. Cryogenics Liquid Helium Liquid Neon		

TABLE VI. GROUND SUPPORT REQUIREMENTS

2.11 Orbital Parameters - The desired orbit inclination is 50° to 60°. An orbit inclination within the limits of 25° to 70° is acceptable. The desired orbit altitude is 500 to 560 kilometers (270 to 300 nautical miles). An orbit altitude falling within 460 to 740 kilometers (250 to 400 nautical miles) is acceptable.

3.0 Programmatics

3.1 Equipment Schedules and Costs - Table VII shows estimated schedules and costs for design, development, test and evaluation of the IR telescope and presently defined experiments.

3.2 Safety Analysis - The necessity for collecting the gaseous neon as part of the IR telescope cooling cycle to avoid release during observations also leads to a need for safe gaseous cryogen collection and periodic venting process. The very low temperatures 2°K and 27.6°K of the liquid helium and liquid neon also present a cold "burn" or freezing type hazard.

3.3 Reliability - Equipment reliability will depend on the level of effort devoted to reliability during design development, fabrication and test phases of the equipment. Failure mode analysis will be limited to identifying single-point failures. Change control will be at the End Item Specification level until the refurbishment phase, and then at the released engineering level.

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)		(2.75)	(3.00)	(2.25)	(2.0)	(0.5)		$ 10.5
PRODUCTION-FIRST ARTICLE			(2.0)	(3.0)	(3.0)	(4.0)		12.0
								$ 22.5

TABLE VII - SCHEDULE AND COST ESTIMATES, INFRARED TELESCOPE

4.0 Notes

4.1 Bibliography - This BEDD contains information obtained from the following documents. No reference to the documents is made in the text.

a. Reference Earth Orbital Research and Applications Investigations (Blue Book), Volume II Astronomy, January 15, 1971

b. Orbital Astronomy Support Facility (OASF) Study, NAS8-2103, McDonnell-Douglas Corporation, Huntington Beach, California, 28 June 1968

c. H. L. Johnson and A. B. Meinel, An All-Sky Survey for Far-Infrared Radiation (50 μm - 800 μm) Associated with High Energy Phenomena, University of Arizona, Tucson, Arizona, 85721; MIT, Cambridge, Mass. 02142; ASE, Inc., Cambridge, Mass, 02142; 27 May 1970

2.7 WIDE COVERAGE X-RAY DETECTOR

ASM-EXP-204-3
May 9, 1972

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

Baseline Experiment Definition Document (BEDD):
ASMDA Wide Coverage X-Ray Detector

Contract GC1-115076

Prepared by:

J. Dawson

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Project Manager

The Bendix Corporation
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Denver, Colorado

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1. INTRODUCTION

The purpose of this document is to define a baseline Wide Coverage X-Ray Detector instrument for the ASMDS.

The scientific objectives, configurations, equipment requirements, physical interfaces, operational requirements, environmental requirements, ground support requirements, and control and display requirements are identified.

2. DISCUSSION

2.1 Scientific Objectives - The Wide Coverage X-Ray Detector surveys a large region of the celestial sphere, on a continuous basis, for unusual transient X-ray emissions. Depending on the intensity of the transient signal, its direction of origin can be determined with an accuracy of 0.01 to 0.05 radian (0.6 to 3 degrees) within a field of up to 2π steradians (one hemisphere).

The instrument is specifically designed to provide a monitoring support function for other X-ray instruments with higher resolution and sensitivity, such as the X-ray and γ-ray arrays, or a stellar X-ray telescope. Additionally, monitoring continuously for transient events involving photons of very high energy (which have been predicted by some cosmological models but have not yet been observed) is an item of high scientific interest.

2.2 Instrument Description - The instrument consists of a large number of identical X-ray detector modules; a sketch of one module is shown in figure 1. Each module has a limited angular sensitivity, approximately 0.25 rad (15°) full-width half-maximum (FWHM), defined by a honeycomb collimator ahead of the X-ray sensitive detector. The modules are mounted on a base structure such that the acceptance field of a module overlaps partially with that of all adjacent modules, to provide a means to estimate the direction of arrival of a burst of X-ray photons.

A typical module arrangement on a dome is shown in figure 2. It is designed to make the angular spacing between adjacent modules as uniform as possible. It is expected that a sufficient number of individual detector modules will be included to provide a celestial coverage equal to that of the X-ray or γ-ray arrays that are also in the payload, mounted on the oriented gimbal.

Each X-ray detection unit consists of a metallic-window proportional counter, backed up with a scintillation detector.

The combination is sensitive to photons in the energy range from 0.32 to 32 fJ (2 to 200 keV). The events detected by each module are sorted according to photon energy with pulse height analyzers, and combined with module identification code. Comparison is made with a threshold (adjustable by the observation crew) and with events detected in other modules. When the preset threshold is exceeded, a console display alerts the observation crew.

The detector units are thermally protected so that no detrimental effects result from direct exposure to solar radiation. The large increase in background count rates that takes place during crossings through the South Atlantic Anomaly and the "radiation belts" will result in automatic power-downs of the detector units. Normal sensitivity is restored when the flux drops back to normal levels.

2.3 Instrument Interfaces and Characteristics - Instrument and support equipment characteristics, and mounting arrangements, are described below. These requirements are tentative, subject to extensive modifications if integration trade studies show that the scientific objectives can be achieved with simpler equipment and requirements.

2.3.1 Equipment Interface Diagram - The interface diagram for the Wide Coverage X-Ray Detector is shown in figure 3. The instrument is hard-mounted on the pallet. Deployment may be used if required to achieve unobstructed viewing. Controls to the instrument and data outputs from the instrument are handled by the Central Data Processor. Thermal control of the instrument equipment is integral to the equipment; heater power is required to maintain the temperature of individual detector modules within the desired range.

2.3.2 Equipment Characteristics - Preliminary equipment characteristics are listed in table I.

2.3.3 Instrument Mounting and Alignment Requirements - The proposed mounting arrangement for the detector modules on a dome-shaped structure is shown in the sketch in figure 2. The central data processor is included within the volume of the mounting structure. The structure maintains the detector unit-to-detector unit alignment within the tolerance of ± 9 milliradians (± 0.5 degree). The arrangement shown in figure 2, where a single dome mounting structure is used to hold all the detector units, is merely one example of several possible mounting methods. The instrument is highly flexible from this viewpoint. The primary constraint is

that it requires unobstructed viewing over a large region of the celestial sphere. Should it be more convenient to do so, the detector units may be mounted on two or more separate supporting structures, as long as the unit -to-unit alignment tolerance of ± 0.009 rad is maintained.

Besides the unit-to-unit alignment tolerances, the instrument's mounting orientation relative to the spacecraft axes must be accurate within 9 mrad (± 0.5 degree).

2.4 Operations - The participation of the crew in the functions associated with this instrument is detailed.

2.4.1 Functional Flow Diagram - A gross outline of the functions required is shown in the functional flow diagram, figure 4. The simplicity of the operational requirement for this instrument is readily apparent from the diagram.

2.4.2 Instrument Preparation Requirements - After the shuttle has achieved stable orbit, and before any functions are performed with the instrument, a safety check of the instrument and support equipment is required. Since all the equipment except the control console is outside the pressurized cabin, the safety check is mostly performed visually through a viewing window.

If possible, the detector units should be calibrated in flight by exposing them to calibration sources of x-ray photons. Should this present severe integration difficulties, the instrument can provide acceptable data if the results from pre- and post-mission calibrations are used.

Calibration and checkout of the electronics in the detector units and central data processor is performed by injecting stimuli at various reference points within the electronics chain. Instrument responses are monitored by the observation crew and recorded by the data management subsystem.

2.4.3 Instrument Operation Requirements - The instrument has two functions:

a. Scientific support for other X-ray and γ-ray detectors included in the payload.

b. Acquisition of scientific data, searching for transient celestial X-ray sources, and measuring the intensity of the diffuse X-ray background

After the instrument has been turned on, checked out, and calibrated, it operates continuously until all observations are complete or until the end of the mission. Crew involvement in the operation and control of the instrument is limited to occasional monitoring of the output data from the controls and displays console, except when the spacecraft is re-oriented.

For any specific orientation of the spacecraft, a number of known intense X-ray sources is observed by the detectors. For purposes of detection of transient phenomena, the known flux from these sources must be biased out in the specific detector units that are affected. This operation can be performed either manually by the observation crew, or by means of a stored program in the central data processor. The frequency of this biasing operation is the frequency with which the spacecraft is reoriented.

2.4.4 <u>Instrument Post Operation Requirements</u> - The only procedure required after operation involves preparation for reentry. This procedure is limited to retracting the instrument (if deployment was used) and turning off electrical power.

2.4.5 <u>Typical Instrument Operation Timelines</u> - Typical operational sequence, and the estimated times involved, are shown in table II. Actual timelines will require real-time scheduling. It is observed that the instrument could operate unattended during the full duration of the scientific portion of the mission.

2.5 <u>Environment</u> - The environmental requirements and constraints associated with the Wide Coverage X-Ray Detector are shown in table III. It will be noted that some of the constraints remain to be specified, due to the early developmental status of this instrument. The general simplicity and ruggedness of the instrument should mean less restrictive specifications than those required for the more sophisticated and more sensitive pointed arrays and telescopes on the same payload. Thermal control of the detector units is self contained. Special coatings and insulating layers, with low absorption to emission ratios, minimize the heating effects of direct solar impingement. Thermostatically controlled heaters maintain the temperatures of modules within the desired range.

2.6 <u>Data</u> - The primary scientific data furnished by the instrument is shown in table IV, together with the auxiliary data required for post-mission data analysis. Table IV represents the complete data package required for this instrument.

The Wide Coverage X-Ray Detector may also be used to provide a monitoring function, to detect the onset of sudden increases in the total flux from variable X-ray sources. For this function, it is necessary to compensate for the known flux from point and diffuse sources. When a spacecraft orientation is selected at the start of an observation period, the constant signal expected in each detector unit must be biased out as a threshold. When the signal rate exceeds the preset threshold by some predetermined value, an alert signal is generated.

The following ranges of threshold rates should be expected:

a. Diffuse X-ray background < 15 photons sec^{-1} $module^{-1}$

b. Sco X-1 (Brightest point source): 300 to 1000 photons sec^{-1} $module^{-1}$.

c. Quiet sun (no flares): 0.3 to 1 x 10^5 photons sec^{-1} $module^{-1}$

d. Solar Flare < 10^7 photons sec^{-1} $module^{-1}$

NOTE: It is anticipated that detectors which include the sun within the field of view will be disabled (high voltage turned off) to preserve the efficiency of the proportional counter sections of the detector unit.

2.7 Pointing - The instrument should be mounted firmly on the spacecraft. Deployment devices may be required to provide adequate viewing capabilities, but gimbals are not required. Once the vehicle orientation has been selected, it must maintain this orientation within ± 9 mrad (± 0.5 degree).

2.8 Controls and Displays - The manner in which real-time scientific data from the Wide Coverage Detector will be displayed to the crewman/astronomer has not been defined. A suggested technique for the support mode consists of a computer generated situation display, figure 5, which can be called up by the crewman with a simple (dedicated) "button." This type of display uses a grid pattern representing the gimbal coordinate system (elevation over azimuth) as a base, and including the fixed viewing restrictions for the array (gimbal limits plus interference from shuttle components). On this grid pattern the following type of data would be superimposed:

a. The location of the source which has triggered the Wide Coverage Detector alert.

b. The orientation of the array's viewing axis.

c. The location of the earth's terminator, showing regions which will soon not be available for viewing.

d. The location of sources selected for viewing by the array.

(optional)e. The orientation of the telescope's axis, and the location of sources selected for viewing by the telescope.

The functional requirements for the controls and displays required to operate the instrument are listed in table V.

2.9 Preflight/Postflight Ground Support - The ground support requirements are detailed. These include equipment and facilities, a brief discussion of the major functions required after instrument installation.

2.9.1 Ground Support Equipment and Facilities - The major facility and equipment requirements are listed in table VI.

2.9.2 Test, Checkout, and Calibration - After instrument installation is completed according to established interface requirements, test and checkout of the complete experiment system as an integral package is required. The procedure for these operations is not defined. Two of the operations that will definitely be required can be identified:

a. Signal test of each detector unit with true X-ray photon flux into the detectors, monitored at the data recording point.

b. Verification of alignment among the detector unit.

A final calibration of the detector characteristics is required prior to launch, and repeated after the instrumentation returns from orbit and before it is dismantled.

2.9.3 Accessibility Requirements - After prelaunch checkout and calibration, access is not required to the scientific equipment if it has not been subjected to environments outside those specified in table III.

2.10 Post-Mission Refurbishment - After completion of a mission in which successful observations were performed, the only refurbishment servicing required will be flushing and replenishment of the gas mixture in the proportional counters that are used in each module.

2.11 Orbital Parameters - The scientific equipment is compatible with all orbits which have been suggested for the Shuttle. The major criteria to be considered in a trade study of orbital parameters are:

a. Minimum ionized particle background flux.

b. Minimum attenuation by atmosphere.

c. Maximum viewing capability of specific sources.

In some respects, the latter two considerations go together, and improve with orbit altitude. In contrast, the particle flux increases with altitude.

3. PROGRAMMATICS

The information in this section consists mostly of subjective estimates which are generally not supported, and probably cannot be supported, by any extensive analysis. Personal experiences with simpler instrumentation have been used for extrapolation into vastly different equipment characteristics.

3.1 Equipment Cost and Schedule - There exist no previous estimates for the cost and schedule requirements for this or any similar instrument. A series of possible estimates are listed in table VII.

3.2 Safety Considerations - As currently designed, all the scientific equipment and the majority of the support equipment (except for the Controls and Displays Console and the tape recorder from the Data Management Subsystem) are located outside the crew compartment. There are no pyrotechnic or explosive devices required. Extravehicular activity is baselined out of the Astronomy Sortie Program. Therefore no safety hazards are anticipated.

3.3 Reliability - Equipment reliability depends primarily on the level of effort devoted to this subject during the design, development, fabrication, and test phases of the equipment.

Probable mean-time-between-failure estimates are given in table VI, for the three types of cost estimates associated with table VIII.

4. NOTES

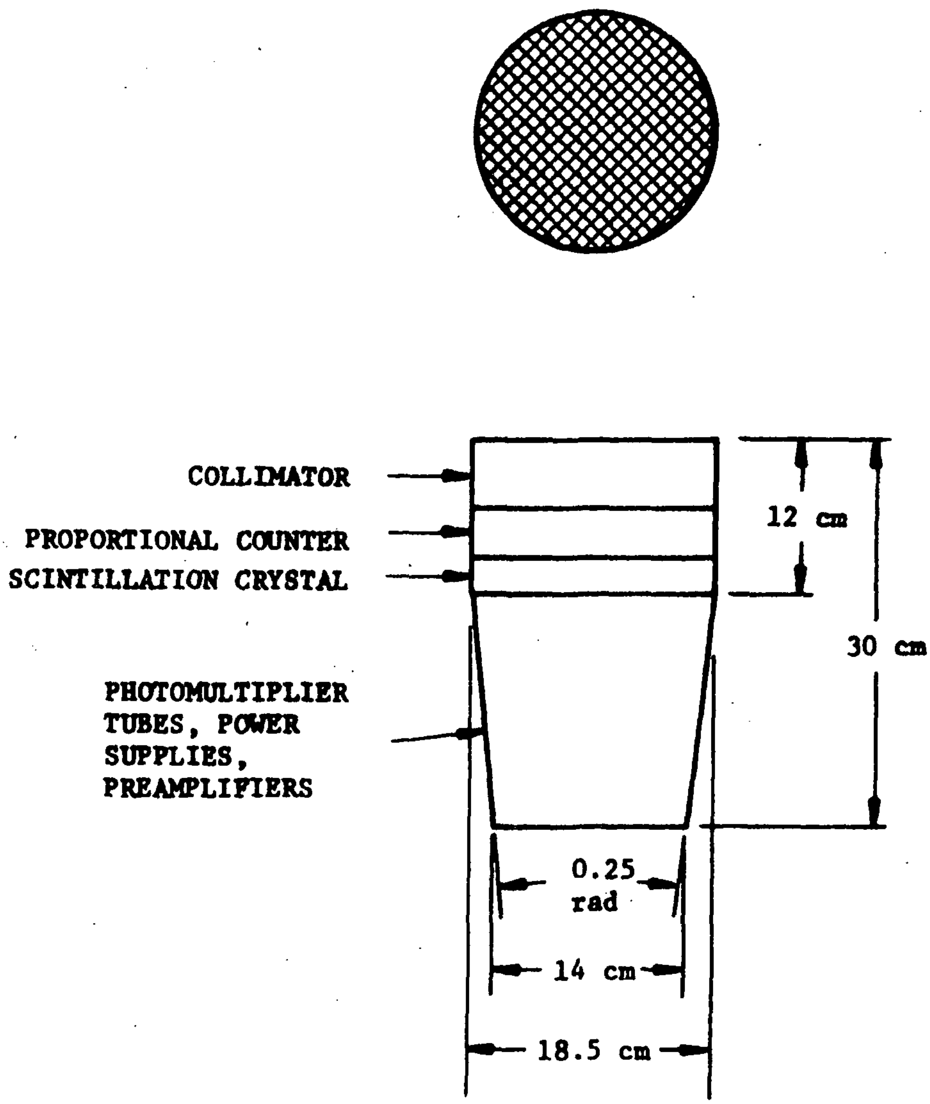
4.1 Bibliography - This report contains information obtained from the following documents. The documents are not referred to in the text.

a. Reference Earth Orbital Research and Applications Investigations, (Blue Book), Volume II, Astronomy, January 15, 1971.

b. LOXT Technical Proposal 2410 - An Experimental Program for Coordinated High Resolution Observations of Cosmic X-Rays, American Science and Engineering, Cambridge, Mass. May 27, 1970.

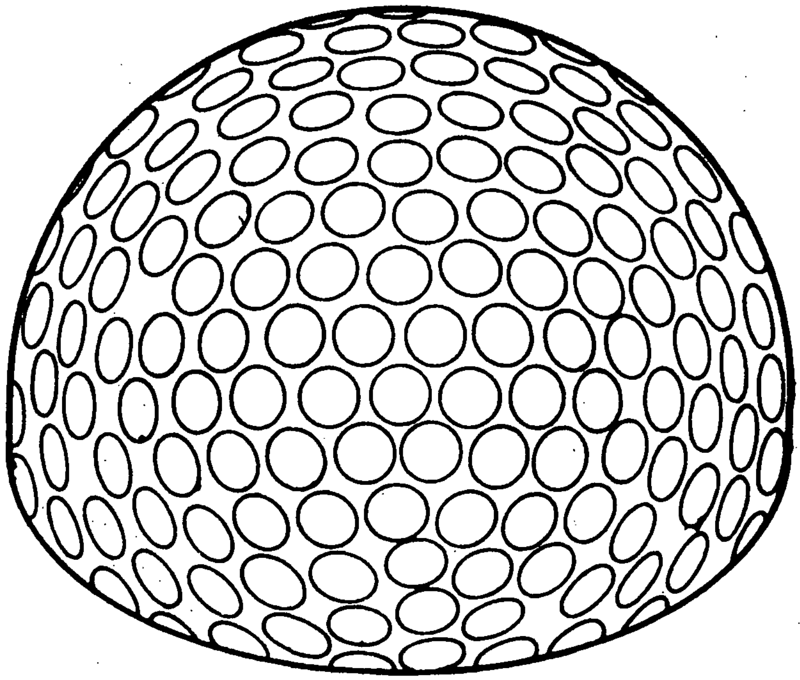
4.2 Abbreviations

ASMDA	Astronomy Sortie Missions Definition Study
BPS	bits per second
C&D	Controls and Displays
cm	Centimeter
CRT	Cathode Ray Tube
fJ	femto-Joule
GMT	Greenwich Mean Time
K	degree Kelvin
keV	kiloelectron volt
kg	kilogram
m	meter
PC	Proportional Counter
PHA	Pulse Height Analyzer
PMT	Photomultipler Tube
rad	radian
RF	radio frequency
RH	
sec	second
sec	arc second
sr	steradian
TBD	To Be Determined
w	watt



Single X-Ray Detector Unit

Figure 1. Wide Coverage X-Ray Detector Unit



Diameter = 2.0 m
(Height = 1.2 m)

Detector Units Mounted on Dome for
Hemispherical Coverage

Figure 2. Wide Coverage X-Ray Detector System

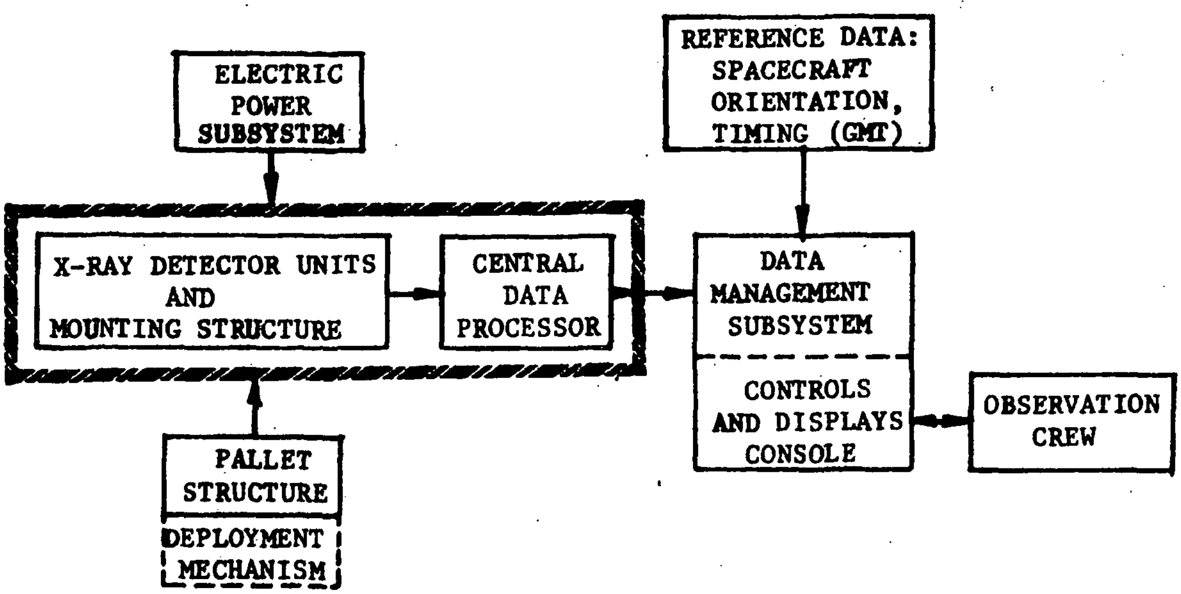


Figure 3. Interface Block Diagram

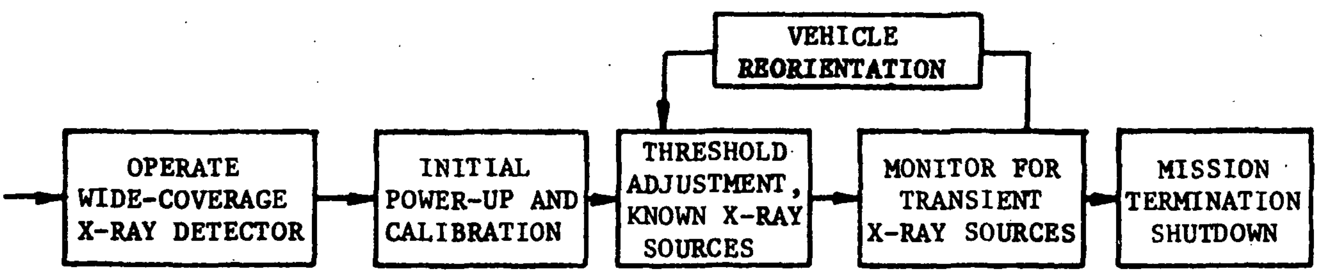


Figure 4. Functional Flow Block Diagram

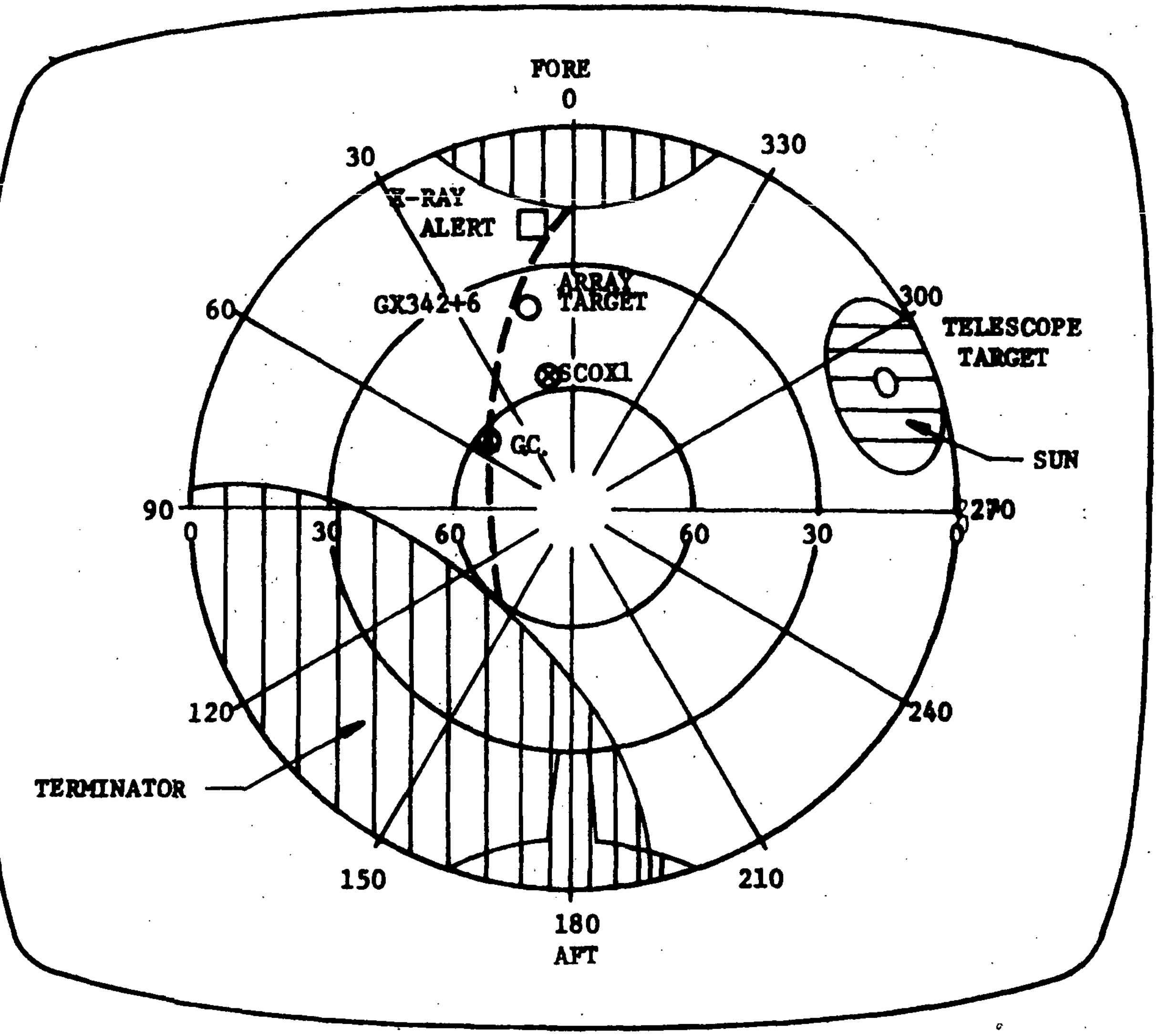


Figure 5. Conceptual Sketch for Situation Display in Gimbal System Coordinates

Table I. Equipment Requirements

	DESCRIPTION	QTY	WIDTH	HEIGHT	LENGTH	DIAMETER	VOLUME	WEIGHT	DATA (bps)	POWER (watts)
	Individual X-Ray Detector Unit	1			30 cm	18.5 cm	0.008 m^3	1.2 kg	-	0.3
EXPERIMENT EQUIPMENT	Units Required for Hemispherical Coverage	(1) 154		120 cm		200 cm	4 m^3	185 kg	(2)	50
	Mounting Dome Structure	1		10 cm (2)		200 cm	(2)	40 kg	-	0-100
	Central Data Processor	1	30 cm	20 cm	60 cm		(2)	25 kg	640	20
SUPPORT EQUIPMENT	Controls and Displays Console	1		TBD						

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NOTES: (1) Actual number of detectors required to be selected to match coverage of X-ray and γ-ray primary detector that is also included in payload, after allowances are made for gimbal freedoms and obscuration by spacecraft equipment.

(2) Part or all of this requirement is lumped somewhere else in this column.

Table II. Typical Operational Timeline

Support Requirements \ Operation Sequence	Initial: Safety Check	Initial: Electrical Power On	Initial: Electrical Check	Initial: Built-in Calibration	Repeated: Enter Spacecraft Orientation	Repeated: Select Detector Unit Biases	Repeated: Monitor for X-Ray Transients	Repeated: Spacecraft Orientation Change	Termination: Turn Off at End of Mission
Time (minutes)	2	1	1	10	1	1	(1)	-	1
Observation Crew	X	X	X	X	X	(2)	(3)	(X)	X
Experiment Equipment: Detector Units and Structure		X	X	X	X	X	X	X	X
Experiment Equipment: Central Data Processor		X	X	X	X	X	X	X	X
Support Equipment: Controls & Displays Console	X	X	X	X	X	X	X	X	X
Power Profile	50	150	150	150	70 to 170				50
Data Profile	-	640	640	640	640	640	640	640	-
Target: Omnidirectional									
Stability: +0.009 rad					X	X	X		

NOTES:
(1) Duration variable, depending on payload operation timeline, from 10 to 600 minutes.
(2) Operation can be automated if memory included in Central Data Processor
(3) Alert signal at C&D console, astronaut involved only if alert is triggered.

Table III. Environmental Requirements/Constraints

		OPERATING	NONOPERATING
MECHANICAL	Acceleration	<10 m sec^{-2} (1g)	Withstands peak values defined for normal launch and reentry.
	Vibration	TBD	
	Acoustic	N/A	TBD
THERMAL	Absolute temperature limits	Detector units: 281 to 285 K (each detector unit includes a heater to maintain the temperature, plus special insulation to handle direct solar exposure)	253 to 293 K
	Differential temperature limits	$\Delta T<2$ K across any module	
ATMOSPHERE	Pressure	$<10^{-1}$ N m^{-2}	$<1.2x10^{5}$ N m^{-2}
	Humidity	-	
	Contaminants	Not affected by normal spacecraft effluents.	Clean-room type environment preferred, 100000 class
EXTERNAL INTERFERENCES	Magnetic Fields	$<2x10^{4}$ tesla at detector unit	TBD
	RF fields	$<10^{-TBD}$ V m^{-1}, $<10^{-TBD}$ W m^{-2}	TBD
	Ionizing particles	<0.1 count sec^{-1} in detector unit. Detectors will require power down in high flux conditions such as South Atlantic Anomaly crossings.	Crossings through South Atlantic Anomaly must not generate delayed radioactivity in surrounding equipment and structures.

Table IV. Recorded Data Requirements

CLASS	DESCRIPTION	FORMAT	READOUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION (2)
SCIENTIFIC:							
X-ray counts from detector units	Detector code, ratemeter setting, counts per sampling interval per energy range bin	serial bit train 20 bits per unit per sample	32 sec^{-1}	640 bps	Continuously after instrument turned on (1)	320 Mbits	20:1
INSTRUMENT HOUSEKEEPING	Up to 500 readout points with commutated sampling	digital 8 bit	2 sec^{-1}	16 bps	(1)	8 Mbits	1:1
SUPPORT EQUIPMENT:							
Proton Flux Detector	Pulse amplitude, code	digital 12 bit	10 sec^{-1}	120 bps	(1)	60 Mbits	1:1
REFERENCE DATA:							
Spacecraft Attitude Angles	IMU signals	digital 3x15 bit	0.01 sec^{-1}	0.45 bps	(1)	10 Mbits	1:1
Timing	Clock reference	digital 20 bit	1 sec^{-1}	20 bps	(1)		

NOTES: (1) Equipment is operating and data is recorded at all times from turn-on to shutdown.

(2) Only data buffering is considered, which requires simple storage and coding techniques. Further compression can be achieved by the use of standard compression algorithms.

Table V. **Preliminary Functions for Wide Coverage X-Ray Detector**

FUNCTION	COMPONENT		NO. REQD
	CONTROL	DISPLAY	
Main Power	Toggle SW	SW Pos	1
Primary HV Power Supply	Toggle SW	SW Pos	1
Threshold Level Adjust	Rotary SW	SW Pos	2
X-Ray Alert		Status Lt	1
Experiment Status	Toggle SW		1
		Status Lt	1
Source Coordinates	Toggle SW		1
		Digital (4)	2
X-Ray Spectrum (PHA)	Toggle SW		1
		Strip Chart	1
Calibration	Toggle SW		1
		Status Lt	1
Rate Attenuator Select	Rotary SW	SW Pos	1
Module HV Power	Rotary SW	SW Pos	2
	Toggle SW	SW Pos	2
Module Integrity		Status Lt	2

Table VI. Ground Support Requirements

EQUIPMENT	Storage Containers
	Handling/Installation Fixture
	Detector Unit Alignment Fixture
	Calibrated X-Ray Sources
	Checkout/Calibration Monitor System
FACILITIES	Clean Room (100 000-class low humidity)
	Prelaunch Environment Control Facility

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)			(0.83)	(1.18)	(0.24)			$ 2.25
PRODUCTION-FIRST ARTICLE			(0.80)	(2.83)	(2.37)	(1.80)		7.80
								$ 10.05

TABLE VII - SCHEDULE AND COST ESTIMATES, WIDE COVERAGE X-RAY DETECTOR

Table VIII. Mean Time Between Failure Estimates

UNIT \ LEVEL	LABORATORY UNITS	SPACE HARDENED	SPACE QUALIFIED
Detector Modules	1 000	5 000	10 000
Mounting Frame	2 000	10 000	25 000
Central Data Processor	1 000	4 000	10 000

<u>NOTE</u>: MTBF values are in hours.

2.8 LARGE AREA X-RAY DETECTOR

ASM-EXP-204-2
15 May 1972

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

Baseline Experiment
Definition Document (BEDD):
ASMDS Large Area X-Ray Detector
(0.1 to 100 keV)

Contract GC1-115076

Prepared by:

J. Dawson

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Approved by:

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Project Manager

The Bendix Corporation
Navigation & Control Division
Denver Facility
Denver, Colorado

CONTENTS

CONTENTS (Concluded)

1. INTRODUCTION

The purpose of this document is to define a baseline Large Area X-Ray Detector (0.1 to 100 keV) (16 aJ to 16 fJ) experiment for the ASMDS.

The experiment objectives, configurations, equipment requirements, physical interfaces, operational requirements, environmental requirements, ground support requirements, and control and display requirements are identified.

2. DISCUSSION

2.1 Scientific Objectives - The Large Area X-Ray Detector will be used to perform measurements of the intensity, spectral distribution, and temporal variations of galactic and extragalactic X-ray sources. Specific items of high scientific interest are:

a. Extragalactic:

1) Spectral distribution of normal galaxies (M 31 and M 33 are typical examples) in the X-ray range.

2) Luminosity and spectral characteristics of Seyfert galaxies (e.g., NGC 1068 - 3C 71) in X rays.

3) Analysis of X-ray emissions from radio galaxies.

4) Absorption characteristics of intergalactic space.

5) Source and intensity of diffuse X-ray background.

b. Galactic:

1) Possible X-ray emission processes active in Sco XR-1, Tau XR-1 (Crab nebula), NP 0532 (Crab pulsar), Cas A (radio source), Sgr XR-1 (Galactic center).

2) Detectability of flare stars, stars with high magnetic fields, planetary nebulae, Wolf-Rayet stars, etc., as X-ray sources.

3) Search for hard X-ray sources, detectable above 15 keV (2.4 fJ) but with low flux below 10 keV (1.6 fJ).

4) Interstellar absorption at X-ray wavelengths, between the solar system and those X-ray sources for which the generation mechanism can be determined.

The Large Area X-Ray Detector is particularly suited to the temporal and spectral analysis of X-ray pulsars. Its high sensitivity also makes it an ideal instrument to study the intermittent X-ray sources, such as flare stars, novae, and supernovae.

2.2 Instrument Description - The detection of low-energy X-ray photons is performed with thin-window, gas-filled proportional counters. For detection of photons in the high energy X-ray range, the proportional counters are backed with scintillation detectors. The proportional counters exhibit good photon efficiency in the 0.2 to 6 keV (30 aJ to 1 fJ) range, with adequate sensitivity for photons of energies between 0.1 and 10 keV (16 aJ to 1.6 fJ). The scintillation counters are sensitive to photons with energies above 10 keV.

The angle of arrival of the incoming X-rays is restricted by means of grid, slat, or honeycomb collimators. The full-width, half-maximum (FWHM) angle of the collimator acceptance pattern is 0.02 radian (1.2 degrees).

Photons arriving at the detectors through the side, without passing through the restricting collimator, are rejected by guard counters arranged around the detectors. Photons entering the instrument from behind the scintillation counters are rejected by means of "phoswich" techniques: an additional layer of scintillating material placed behind the primary scintillation detector. The combination of the two scintillators can be used to identify the direction of photon penetration.

The complete instrument consists of multiple collimator-detector modules, mounted on a structural frame, with co-aligned orientation. Typical dimensions for each module are shown in figure 1. The actual number of modules included can be adjusted according to the subsystem support capabilities.

The effective X-ray sensitive capture area of each module with dimensions as shown in figure 1 is 0.35 m^2; a sensitive area of 2 m^2 is achieved by combining six modules. This total sensitive area would represent an instrument with excellent scientific and observational potential. If a greater total sensitive area can be accommodated, it should be considered in the program.

The instrument must be mounted on gimbals to provide freedom to orient the sensitive axis independent of the carrier vehicle's orientation constraints and to decouple the instrument from the shuttle's angular drifts. If a standard gimbal design is incapable of accommodating all six modules, it is acceptable to separate the instrument into two or more portions mounted on separate gimbal systems which are slaved together.

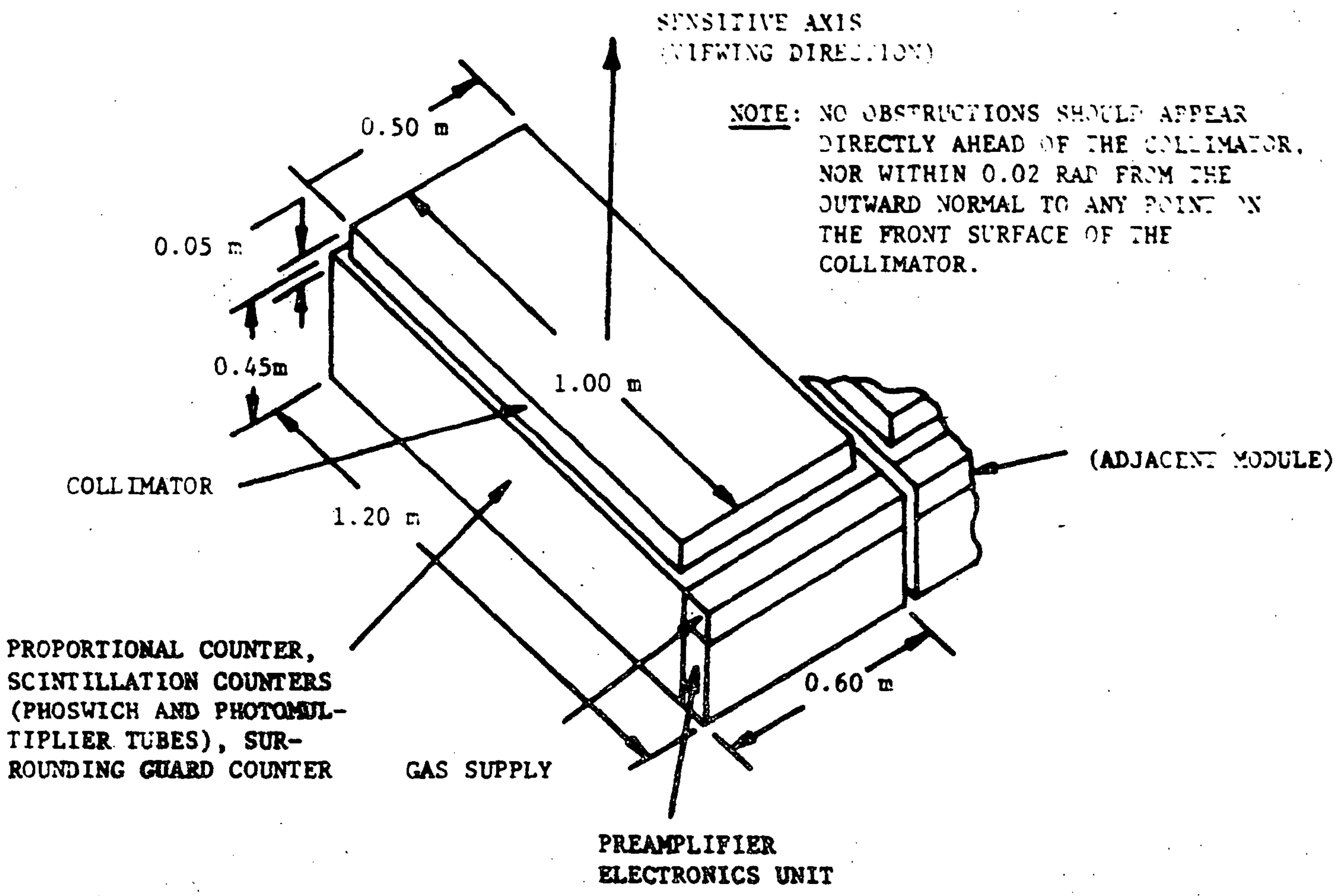

Figure 1. Typical Dimensions of Individual Module, Large Area X-Ray Detector

To retain adequate transmission at the low energy range, the proportional counter windows must be extremely thin and cannot be provided with thermal covers for protection. The instrument's axis must not be pointed closer than $\pi/4$ radian (45 degrees) to the sunline.

Figure 1 shows a preamplifier unit associated with each module, to develop adequate signal levels. A central data processor is also required to provide pulse-height analysis of the detector signals. Timing signals referenced to GMT are required at the processor, with maximum error of 1 msec. A gas supply at each module provides the capability of replenishing the gas in the proportional counters.

2.3 Physical Configuration and Power Requirements - Descriptions of experiment and support equipment characteristics and mounting arrangements follow. These requirements are tentative, subject to extensive modifications if integration trade studies show that the scientific objectives can be achieved with simpler equipment and requirements.

2.3.1 Interface Block Diagram - The equipment interface diagram is shown in Figure 2. This diagram identifies the major interfaces between the instrument and the spacecraft subsystems.

2.3.2 Scientific Equipment Characteristics - Preliminary scientific equipment characteristics are listed in Table I.

2.3.3 Support Equipment Characteristics - Preliminary estimates of the characteristics of the support equipment required for this instrument are listed in Table II.

2.3.4 Instrument Mounting and Alignment Requirements - The proposed mounting arrangement for six collimator modules is shown in the sketch of figure 3. Each module is 1.2x0.6x0.5 m. An array of six modules is therefore about 2.4x1.8 m. It may not be feasible to mount six modules on a single gimbal because of the size and mass. In that case, a cluster of three modules might be mounted on a gimbal, and two such clusters with gimbals provided. An alternate choice is to accept a reduced collecting area (with resultant loss in sensitivity) and use only three or four collimator modules mounted on a single gimbal.

The Wide-coverage X-ray Detector is not shown in figure 3. It is mounted in a fixed position on a pedestal in the shuttle bay. Gimbals are not required. Ideally, hemispherical coverage is desired for both the Wide Coverage X-ray detector, and the gimballed Detector Module Array. Practically, coverage will be reduced by interference or obstruction by the structure of the space shuttle.

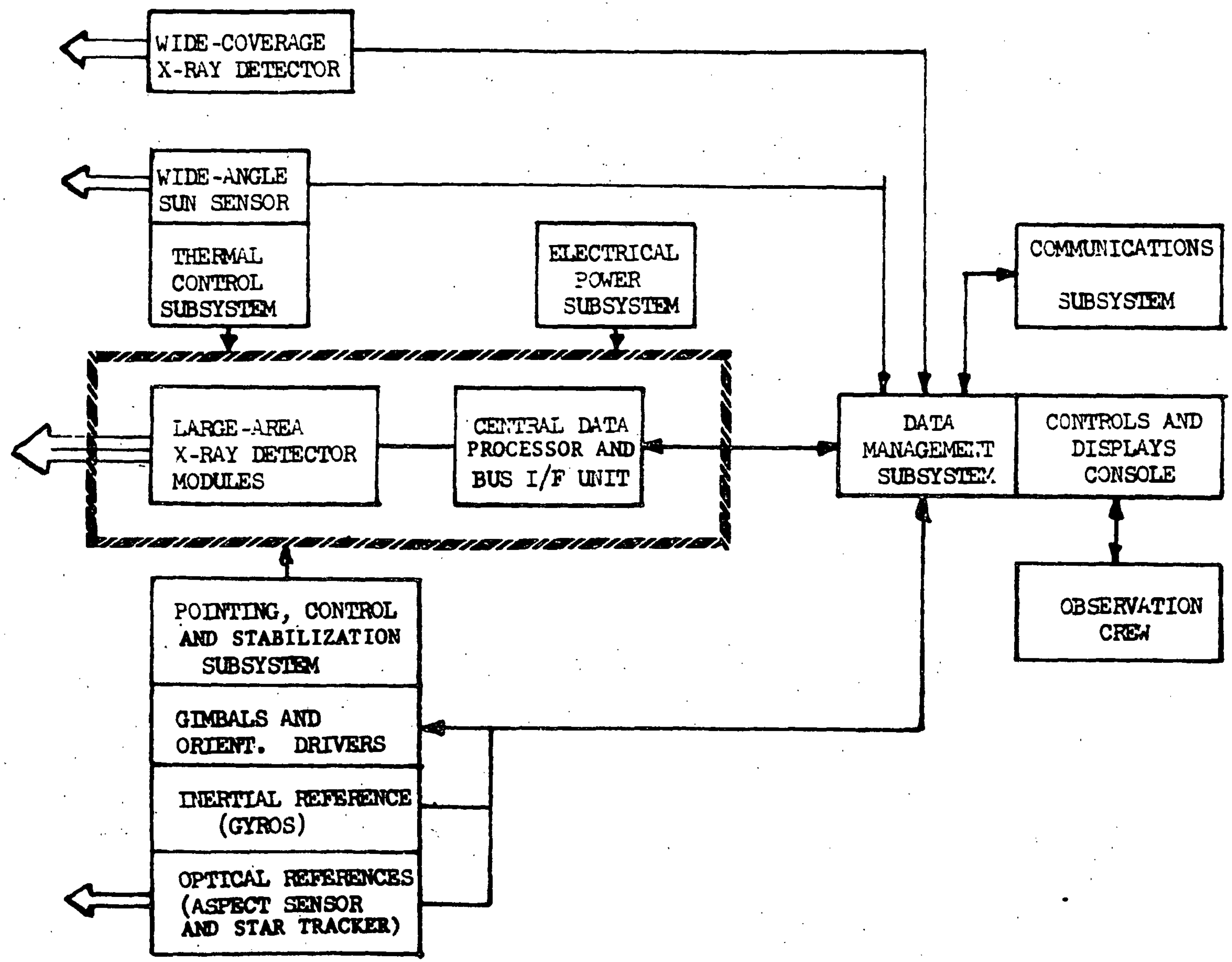

Figure 2. Interface Block Diagram

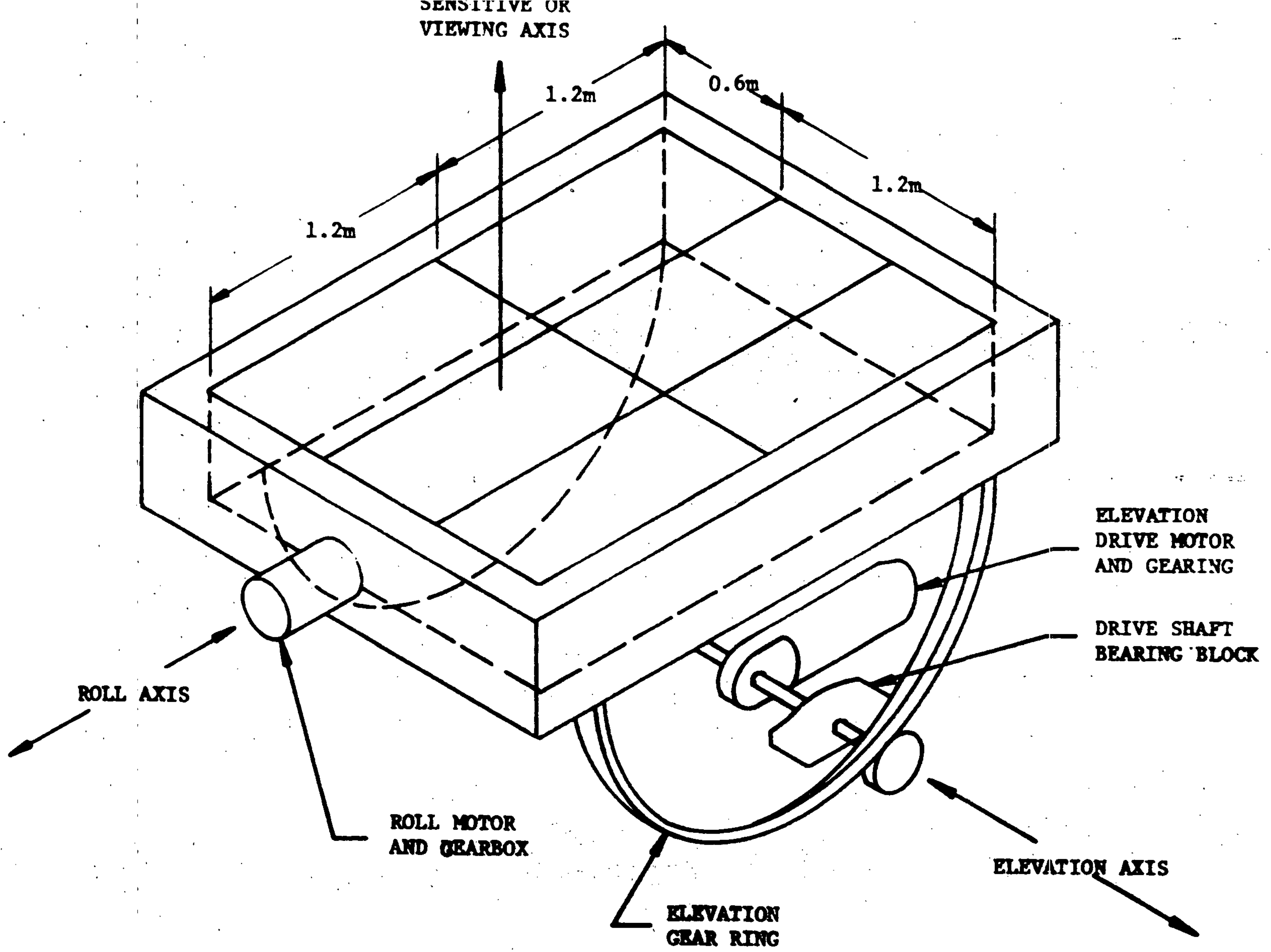

Figure 3. Instrument Mounting Arrangement

Alignment requirements are 0.2 degrees between individual detector modules of the array,.and also with respect to the pointing axis of the array. The alignment between the Wide-coverage Detector and the gimballed array should be 0.5 degrees. These alignments are sufficiently coarse so that in-orbit alignment trims are hopefully unnecessary; alignment will be performed on the ground as part of the installation and checkout procedure.

2.4 Operations - The participation of the crew in the functions associated with this experiment is described in this section.

2.4.1 Functional Flow Diagram - A gross outline of the functions required is shown in figure 4.

2.4.2 Instrument Preparation Requirements - After the Shuttle has achieved stable orbit, a visual safety inspection is conducted through a viewing window in the pressurized cabin. The proportional counters of the detector modules are then vented and purged, and refilled with gas. Each module has its own gas supply for replinishment and re-filling. (The purge and refilling prior to operation may not be necessary, and it would be desirable to eliminate this step. The necessity of re-filling depends upon the gas used, the hazards involved in launching with an inflammable gas in the counters, and the techniques of calibration on the ground before launch).

Electrical power is then turned on from the control console, applying to the low voltage power supplies and data processing equipment only. Operation of the digital counters, and the pulse height analyzer is then checked using a test signal generator, and a CRT display on the control console. Amplifier gains and discriminator levels are adjusted if required. With the electronic pulse processing operation verified, the high voltage power supplies are switched on individually, in sequence for each detector module. The astronaut watches for evidence of malfunction, such as corona discharge, other short circuits, and excessive count rates. Alternate power supplies may be tried in case of malfunction.

Calibration of the detector modules is then performed. Radioactive sources mounted on control rods are inserted in each detector module in turn, and the resulting data output observed on the count rate meters and PHA located on the control console. Very likely, the detector modules may adjust gain automatically, so the astronaut serves only to monitor the adjustments, and to control insertion and withdrawal of the calibration sources from the console.

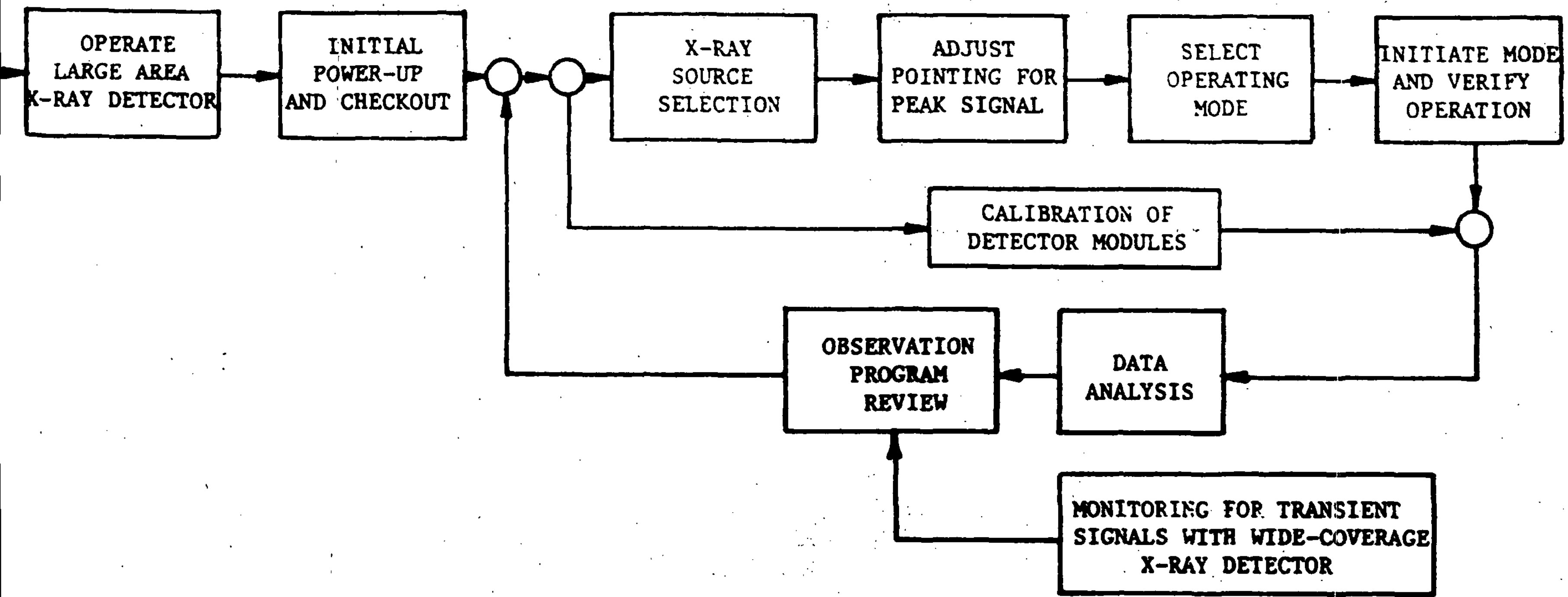

Figure 4. Functional Flow Diagram

A similar checkout and calibration procedure is then conducted for the Wide Coverage X-Ray Detector.

Celestial orientation references must be established in the experiment system. The Shuttle orientation data are combined with the celestial coordinates of a selected celestial source to define the gimbal angles required for acquisition by the aspect sensor/star tracker that is mounted on the same gimbal. The star tracker is used for automatic tracking, and the operation of the automatic tracking subsystem is checked and possibly trimmed at this time.

The launch restraints are released, the entire array is pointed at a reference X-ray source. Acquisition is verified for each detector module, if possible.

Alignment among the six detector modules may be checked, and modules badly misaligned turned off. (It is assumed that no adjustments for module alignment in orbit will be provided. However, should some provision be made for remote adjustment of alignment, such adjustments might be performed at this point).

The experiment is now ready for scientific data taking.

2.4.3 Observational Data Requirements - The scientific objectives described in section 2.1 define this instrument's primary observational functions as detailed analyses of specific, known or anticipated, X-ray sources. No survey operations are contemplated; the expected operational date for this instrument on the ASM program postdates the HEAO-A mission, and therefore the full-coverage sky surveys for discrete X-ray sources will have been completed.

The key item in the observation of faint and unusual X-ray sources is the statistical accuracy of the data. X-ray photons are individually analyzed and counted, so that the statistical uncertainty of the data is proportional to the inverse one-half power of the total number of photons that are counted: $\sigma \propto N^{-1/2}$. The number of photons counted corresponding to an energy interval ΔE is determined by the product of the flux, $f_{\Delta E}$, from the source within the interval ΔE, the effective capture area A of the observing instrument, and the time that the source is observed:

$N(\Delta E)=F_{\Delta E}\cdot A\cdot t$. To obtain data of adequate statistical accuracy ($\sigma<1\%$ or $N>10^4$) from sources of low flux, long observation times are required. It is expected that most of the X-ray source measurements performed with the Large Area X-Ray Detector will consist of observations lasting 1 000 seconds or longer on each source.

The instrument has two primary operational modes:

a. Spectral - Photons detected by all modules are sorted according to energy and counted.

b. Temporal - All photon data received is recorded on a wideband channel for pulsar analysis.

Each of the two primary modes could be further classified into several submodes, which are selected by the observation crew; all submodes within a mode present the same interface requirements.

After orienting the detector to the source of interest, slight pointing adjustments are made to peak the output signal. For sources of moderately high and constant flux, this function can be either manual or automatic.

The Wide-Coverage X-Ray Detector monitors a wide region of the celestial sphere for unusual transient X-rays. This support instrument alerts the crew to transient X-ray phenomena, and provides approximate celestial coordinates of the event for further observation and analysis with the Large Area X-Ray Detector.

A calibration mode is also included, which is exercised periodically by the crew. Controlled stimuli are supplied to the detector modules to calibrate sensitivities and gains.

Each observational period is followed by a "quick-look" analysis of the data acquired. In this manner, instrument performance is monitored regularly. Upon completion of the quick-look analysis, a review of the observational program is made to identify the sources with high priority that can be observed by the Large Area X-Ray Detector without disturbing the orientation of the high-resolution telescope.

In observing a series of intense sources, the gas in the proportional counters may become exhausted. Scientific data-taking must then be interrupted to purge the counters, and refill with gas. Calibration is required following the refill.

2.4.4 Instrument Post-Operation Requirements - The major post-operation functions are as follows:

a. Shut down electrical power. First, the high-voltage power supplies are turned off, then the data processing circuitry is cleared.

b. Vent the proportional counters of the Large Area X-Ray Detector (if deemed necessary for safety).

c. Place the experiment in launch orientation and reset the launch restraints.

d. Turn off all electrical power, except perhaps for temperature monitoring.

All operations are performed by the crew using the Control & Display console.

2.4.5 Typical Instrument Operation Timelines - The experiment operational characteristics described in the above paragraphs are summarized in table III.

2.5 Environmental Requirements and Constraints - The environmental requirements and constraints associated with this experiment are listed in table IV.

Count rate limiters will automatically disable the proportional counters and scintillation detectors during crossings of the South Atlantic Anomaly; detectors will return to normal operation automatically when the particle flux drops below a preset threshold.

The membranes covering the proportional counters are very thin, and can withstand only 0.3 atm differential pressure at the most. (Operating pressure will be about 3 psi). Therefore the counters must be filled to 1.0 to 1.2 atm on the ground, and vented carefully during launch. For safety reasons, the fill gas during ground operations must be non-flammable, irrespective of the operating gas used in orbit.

2.6 Data - The primary scientific data is described in table V, together with the auxiliary data required. This complete data package represents the basic information which will be used to achieve the specified scientific objectives of the instrument.

In addition to the recording of this data, it must be available for real-time monitoring at the Controls and Displays Console, as defined in 2.8.

The possibility of in-flight support by ground-based scientific personnel must be included. Ground support of this type will interface with the crew through the voice link. It is anticipated that all commands to the scientific and support equipment will be performed by the crew through the Controls and Displays Console.

Reference timing signals must be available which can be correlated to GMT with absolute errors no greater than 1 msec.

2.7 Pointing - The full-width half maximum angle of acceptance of the individual detector modules is 0.02 radians (1.2 degrees). This implies that the accuracy of pointing should be 0.01 radians or better, preferably 0.004 radians (about 14 arc minutes). The axis of the experiment (Large Area X-Ray Detector) is to be pointed about the two axes orthogonal to the experiment axis. The permissible drift is less than the accuracy of pointing, and is tentatively established as 0.001 radians (about 5 arc minutes). The consequence of angular drift is to introduce a slowly-varying change in the intensity of the signal output. Currently, there is no requirement on angular rate.

The Large-Area X-Ray Detector should be mounted on gimbals which afford as nearly a hemispherical coverage of the sky as possible from the shuttle bay. The minimum coverage acceptable is 120 degrees in each coordinate. In addition to providing a pointing capability with the required stability, it is required to slew the instrument from one source to another at a rate of at least 0.02 rad sec^{-1} (about 1.2 degrees per second) and preferably 0.05 rad sec^{-1} about both gimbal axes. It is assumed that targets of interest will be 20 degrees apart on the average, and that two targets per orbit will be observed. Finally, the gimbal drive is used to restore the experiment to a suitable orientation for engagement of launch restraints, and re-entry.

2.8 Controls and Displays - The functional requirements for the controls and displays required to operate the instrument are listed in tables VI and VII. Table VI lists the requirements for the scientific equipment, and table VII lists the requirements for the support equipment.

2.9 Preflight/Postflight Ground Support - The ground support requirements are detailed. These include equipment and facilities, and a brief discussion of the major functions required after instrument installation.

2.9.1 Ground Support Equipment and Facilities - The major facility and equipment requirements are listed in table VIII.

2.9.2 Test, Checkout, and Calibration - After instrument installation is completed according to established interface requirements, test and checkout of the complete experiment system as an integral package is required. The procedure for these operations is not defined. Some of the operations that will definitely be required can be identified:

a. Signal test of each module with true X-ray photon flux into the detectors, monitored at the data recording point.

b. Checkout of pulse processing circuitry (i.e., counters, pulse height analyzers, buffer registers) with simulated signals.

c. Verification of alignment among the six detector modules.

d. Operational verification of the gimbal/detector module system for slewing rates, accuracies of pointing.

e. Star sensor images at Controls and Displays Console. Verification of alignment with detector modules.

A final calibration of the detector characteristics is required prior to launch, and repeated after the instrumentation returns from orbit and before it is dismantled.

2.9.3 Accessibility Requirements - After prelaunch checkout and calibration, access is not required to the scientific equipment if it has not been subjected to environments outside those specified in table IV.

2.10 Post-Mission Refurbishment - After completion of a mission in which successful observations were performed, the only refurbishment servicing required will be flushing and replenishment of the gas mixture in the proportional counters that are used in each module.

2.11 Orbital Parameters - The scientific equipment is compatible with all orbits which have been suggested for the Shuttle. The only criteria to be considered in a trade study of orbital parameters are:

a. Minimum ionized particle background flux.

b. Minimum attenuation by atmosphere.

c. Maximum viewing capability of specific sources.

In some respects, the latter two considerations go together, and improve with orbit altitude. In contrast, the particle flux increases with altitude.

3. PROGRAMMATICS

The information in this section is based upon current cost and reliability targets for the LAXRAY experiment for the High Energy Astronomical Observatory (HEAO), together with personal conjecture. Proportional counters of the size planned for this experiment have never before been built and flown on a space mission. However, much smaller and somewhat simpler proportional counters have been flown on small satellites and in rockets. The HEAO experiment is relevant because the LAXRAY experiment is very similar in design to the Large Area X-Ray Counter discussed herein for the Space Shuttle ASM.

3.1 Equipment Cost and Schedule - There are two available cost estimates which form the basis for the estimates given in table IX. The estimate for LAXRAY for HEAO is a goal of $7.8 million, of which about 0.5 million is for analysis of the data output, and not applicable here. The other estimate was that published in the Shuttle Payload Planning Activity, which was $10 million. Of this $10 million, $5 million is for updating and refurbishment of the experiment for repeated flights over a 10 yr. period. The total cost of development alone for the ASM is estimated to be $12.7 million, plus another $5 million for refurbishment for subsequent flights. Drawing upon the HEAO design and flight experience, a development period of 4 years is anticipated.

3.2 Safety Considerations - All scientific equipment and a majority of the support equipment (except for the Control & Displays Console and the tape recorder) are located outside the crew compartment. There are no pyrotechnic or explosive devices required, and no EVA is scheduled.

The experiment incorporates several high-pressure gas reservoirs for re-charging the gas counters. The gas planned for HEAO is propane, a high inflammable gas. Very likely, inert gases such as argon and xenon would be required for a manned space flight.

There is a hazard of rupture of the gas reservoirs, especially during the boost and re-entry. The reservoirs will be at least 15 feet from the cabin bulkhead, and danger to the crew can be reduced by using shields to deflect fragments away from the cabin.

3.3 Reliability - The HEAO version of a Large Area X-Ray Array is to be designed for a 2-year lifetime, approximately 20,000 hours. Very likely, it will be more economical to retain the HEAO design than to re-design for a shorter life-time. The probable mean-time-between-failure estimates are given in table X, for the two types of cost estimates associated with table IX.

4. NOTES

4.1 Bibliography - This report contains information obtained from the following documents. The documents are not referred to in the text.

a. Reference Earth Orbital Research and Applications tigations (Blue Book), Volume II, Astronomy. January 15, 1971.

b. A Proposal to Fly Large Area X-Ray Counters and Associated Hardware Aboard the HEAO, Naval Research Laboratory, Washington D.C., P9-70. May 28, 1970.

4.2 Abbreviations

ASMDS	Astronomy Sortie Missions Definition Study
aJ	atto-Joule
avg	average
bps	bits per second
cm	centimeters
CRT	Cathode Ray Tube
fJ	femto-Joule
FWHM	Full-width, half-maximum
GMT	Greenwich Mean Time
HSKPG	Housekeeping
I/F	Interface
INCL	Including
K	degrees Kelvin
kbps	kilobits per second
keV	kiloelectron volt
kg	kilogram

m	meter
msec	millisecond
ORIENT.	orientation
PC	Proportional Counter
PHA	Pulse Height Analyzer
pk	peak
PMT	Photomultipler Tube
rad	radian
RF	radio frequency
sec	second
sec	arc second
sr	steradian
TBD	To Be Determined
TV	Television
w	watt
W.A.S.S.	Wide Angle Sun Sensor

Table I. Experiment Equipment

DESCRIPTION	QTY	WIDTH	HEIGHT	LENGTH	DIAMETER	VOLUME	WEIGHT	POWER (WATTS)
DETECTOR MODULES	(6)	2.40 m	0.50 m	1.80 m	-	2.2 m^3	240 kg	60
CENTRAL DATA PROCESSOR	1	0.30 m	0.30 m	0.90 m	-	0.08 m^3	25 kg	40
SUPPORT STRUCTURE	1	2.50 m	-	2.00 m	-	-	~50	-

RJS 8/22/72

WEIGHT TOTAL (SI): ~ 315 KG

Table II. Support Equipment

DESCRIPTION	QTY	WIDTH	HEIGHT	LENGTH	DIAMETER	VOLUME	WEIGHT	POWER (WATTS)
WIDE-COVERAGE X-RAY DETECTOR	1	-	1.2 m	-	2.0 m	1.8 m^3 (hemi-sphere)	250 kg	40
THERMAL CONTROL (INCL W.A.S.S.)	1	TBD						20–100 w 100 avg Δ=200 pk
GIMBAL MOUNT (INCL REFERENCE SYSTEMS: GYROS, ASPECT SENSOR STAR TRACKER)	1	2.0 m	1.5 m	2.9 m	-	Not de-fined	~500 kg	30
CONTROLS AND DISPLAY CONSOLE	1	0.5 m	1.1 m	0.7 m	-	0.4 m^3	200 kg	130 w

VALUES SHOWN ARE ENGINEERING ESTIMATES BASED ON CURRENT DESIGNS.

Table III. Typical Operational Timelines

	SUPPORT REQUIREMENTS / EXPERIMENT OPERATING SEQUENCE	INITIAL													REPEATED						(OCCASIONAL)					FINAL				
		SAFETY CHECK	VENT/PURGE DETECTORS	COUNTER GAS REFILL	ELECTRICAL POWER ON	DATA PROCESSOR CHECK	DETECTOR HV ON	DETECTOR CHECK	CALIBRATION	WIDE COVERAGE X-RAY DET	RELEASE LAUNCH RESTRAINTS	STAR SENSOR ORIENTATION	GYRO REFERENCES	ALIGNMENT CHECK	SELECT TARGET	ORIENT (SLEW) DETECTOR	ACQUIRE TARGET	DATA ACQUISITION	QUICK-LOOK DATA ANALYSIS	OBSERVATION PROGRAM REVIEW	DETECTOR POWER OFF	VENT/PURGE DETECTORS	COUNTER GAS REFILL	DETECTOR POWER ON	CALIBRATION	DETECTOR POWER OFF	VENT DETECTORS	GIMBALS TO LAUNCH POSITION	RESET LAUNCH RESTRAINTS	ELECTRIC POWER OFF
	TIME (MINUTES)	5	300	90	1	30	1	9	30	10	5	5	2	30	2	1	2	10 to 300	10	20	1	300	90	1	30	1	300	1	1	1
	CREW	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SCIENTIFIC EQUIPMENT	DETECTOR MODULES	X	(X)	(X)	X	*	X	X	X	*	*	*	*	X	*	*	X	X	*	*	X	(X)	(X)	X	X	X	X			
	CENTRAL DATA PROCESSOR	X			X	X	X	X	X	*	*	X	X	X	*	*	X	X	X	X	X			X	X	X				
	GAS RESUPPLY	X	X	X																		X	X				X			
	SUPPORT STRUCTURE (INCLUDES THERMAL CONTROL)	X			X	X	X	X	X	X	X	X	X	X	*	X	X	X	X	X	*	*	*	X	X	*	*	X	X	
SUPPORT EQUIPMENT	WIDE COVERAGE X-RAY DETECTOR	X								X	*	X	X	X	X	X	X	X	*	*	X			X	*	X				
	GIMBALS	X										X	X	X	*	X	X	X	*	*	X			X	*	*	*	X	X	
	STAR SENSOR	X										X	X	X	X	X	X	X	X	X	X			X	*	X				
	GYROS	X			X	*	*	*	*	*	*	X	X	X	X	X	X	X	X	X	X			X	*	*	*	X	X	
	CONTROL & DISPLAY	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

* EQUIPMENT NOT SPECIFICALLY REQUIRED FOR THIS FUNCTION, BUT REMAINS TURNED ON AND DRAWING POWER.
(X) VALUES IN PARENTHESIS MAY NOT BE REQUIRED.

Table IV. Environmental Requirements/Constraints

		OPERATING	NONOPERATING
MECHANICAL	Acceleration	Not susceptible to sustained acceleration.	Withstands normal launch and re-entry environments without damage.
	Vibration	Specific frequencies may cause resonances.	
	Acoustic	TBD	
THERMAL	Absolute temperature limits	291 to 295 degrees K	263 to 303 degrees K
	Differential temperature limits	2 degrees K across any module	10 degrees K across any module
ATMOSPHERE	Pressure	10^{-5} Nm^{-2}	Not critical, but differential pressure must be controlled to 0.3 atm.
	Humidity	N/A	40% RH
	Contaminants	Not too sensitive	100,000 clean room specifications
EXTERNAL INTERFERENCES	Magnetic fields	0.1 millitesla at photomultiplier tubes.	Not critical
	RF fields	TBD	TBD
	Ionizing particles	Background less than 10^{-7} cm^{-2} sec^{-1}. Requires shut-down when crossing South Atlantic Anomaly.	Induced radioactivity must not occur.

CLASS	DESCRIPTION	FORMAT	READOUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION
SCIENTIFIC	Count pulses 1 Encoded digital Count Rate Meter	Digital 10 bit word	400 sec^{-1}	4000 bps	Continuous (Experiment includes buffer)	2000 MBits	N/A Incorporates modes of different compression
INSTRUMENT HOUSEKEEPING	Temperature Voltages, Pressure 200 points	Digital 8 bit	10 sec^{-1}	160 bps	2	70 MBits	1:1
CREW'S ANNOTATION	Voice Log book	"analog" written	as req'd	3 kHz	2	120-144 hrs	-
SUPPORT EQUIPMENT: Wide Coverage X-Ray Detector	Signal pulses + code	Digital 16-bit	32 sec^{-1}	640 bps	2	320 MBits	20:1 or more
SUBSYSTEMS: Spacecraft Attitude Angles	IMU signals	Digital 3x15 bit	0.01 sec^{-1}	0.45 bps	2	17 MBits	1:1
Gimbal Angles	Angular encoders	2x15 bit	0.05 sec^{-1}	1.5 bps	2		
Star Tracker	Offset; error angles	2x8 bit	0.05 sec^{-1}	0.8 bps	2		
Rate Gyros	Rates	2x10 bit		10 bps	2		
Timing	Clock reference	20 bit	1 sec^{-1}	20 bps	2		

1 Experiment data processor encodes all information digitally.

2 Equipment operates at all times between turn-on and shutdown. Standby modes not yet defined, if any.

Table VI. Scientific Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
MAIN POWER	ON/OFF	ON/OFF
HV POWER	ON/OFF (6)	ON/OFF (6)
OPERATING MODE	SELECTOR SWITCH (5 positions)	LIGHTED PANEL (5)
CALIBRATION	SOURCE IN/OUT (3)	LIGHTED PANEL (3)
DISCRIMINATOR LEVELS	RAISE/LOWER SELECTOR SWITCH (3) (15 position)	DIGITAL METER
HV POWER ADJUST	RAISE/LOWER SELECTOR (6 position)	DIGITAL METER
LOW VOLTAGE ADJUST	RAISE/LOWER SELECTOR (3 position)	
COUNT RATE		DIGITAL METER
X-RAY SPECTRUM (PHA)	TBD	CRT ANALOG
INDIVIDUAL COUNTER EVALUATION	SELECTOR (6)	CRT ANALOG
GAS PURGING AND RESUPPLY	VALVES OPEN/CLOSE (12)	ANALOG METER (6)
THERMAL CONTROL	ON/OFF ADJUST TEMPERATURE METER SELECTOR (12 positions)	ANALOG METER (2)
LAUNCH RESTRAINTS	OPEN/CLOSE/LOCK	INDICATOR LIGHTS (6)

Table VII. Support Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
GIMBAL SYSTEM:		
MAIN POWER	ON/OFF	ON/OFF
PRIMARY INSTRUMENTATION	ON/OFF	ON/OFF
SHUTTLE CELESTIAL ORIENTATION	-----	DIGITAL (RA+δ)
GIMBAL ANGLES	+/-(2)	DIGITAL
FIELD OF VIEW ORIENTATION	-----	DIGITAL (RA+δ)
SOURCE MAP	ON/OFF	CRT(?)
STAR SENSOR OFFSETS	+/-(2)	DIGITAL
STAR SENSOR FIELD	ON/OFF	CRT(?)
STAR SENSOR LOCK ON	ON/OFF	INDICATOR
WIDE-COVERAGE X-RAY DETECTOR:		
MAIN POWER	ON/OFF	ON/OFF
PRIMARY HV POWER SUPPLY	ON/OFF	ON/OFF
THRESHOLD LEVEL ADJUST	50 LEVELS	LEVEL
X-RAY ALERT	-----	ON/OFF
EXPERIMENT STATUS	START/STOP	READY/OPERATE
SOURCE COORDINATES	ON/OFF	(2) DIGITAL
X-RAY SPECTRUM (PHA)	ON/OFF	ANALOG
CALIBRATION	START/STOP	CALIBRATION ON/OFF
RATE ATTENUATOR SELECT	1-6	1-6
MODULE HV POWER	OFF (154 MAX)	-----
MODULE INTEGRITY	-----	GO/NO-GO

Table VIII. Ground Support Requirements

EQUIPMENT	Controlled Environment Storage Container
	Handling/Installation Fixture
	Module Alignment Fixture
	Calibrated X-Ray Sources
	Checkout/Calibration Monitor System
FACILITIES	Clean Room (100 000-class low humidity)
	Prelaunch Environment Control Facility
	Dry nitrogen purge
	Proportional counter gas for ground checkout of counters

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH								
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)			(1.70)	(1.75)	(1.30)	(0.20)		$ 4.95
PRODUCTION-FIRST ARTICLE				(1.25)	(1.93)	(1.40)		4.58
								$ 9.53

TABLE IX - SCHEDULE AND COST ESTIMATES, LARGE AREA X-RAY DETECTOR

Table X. Mean-Time-Between-Failure Estimates

UNIT \ LEVEL	SPACE HARDENED	SPACE QUALIFIED
Detector Modules	8,000 Hrs	12,000 Hrs
Central Data Processor	10,000	10,000
Mounting Frame	10,000	20,000

2.9 LARGE MODULATION COLLIMATOR

ASM-EXP-204-4
June 1, 1972

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

Baseline Experiment Definition Document (BEDD): ASMDS Large Modulation Collimator (0.1 to 100 keV)

Contract GCl-115076

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Denver Facility
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CONTENTS

CONTENTS (Concluded)

1. INTRODUCTION

The purpose of this document is to define a baseline Large Modulation Collimator (16 aJ to 16 fJ) (0.1 to 100 keV) experiment for the ASMDS.

The experiment objectives, configurations, equipment requirements, physical interfaces, operational requirements, environmental requirements, data, pointing, ground support requirements, control and display requirements, and post-mission refurbishment requirements, are identified.

2. DISCUSSION

2.1 Scientific Objectives - The Large Modulation Collimator will be used to investigate two specific aspects of X-ray sources:

a. The fine structure and angular dimensions of the sources.

b. The precise location of these sources in the celestial sphere, to enable their identification with objects observed in optical wavelengths.

2.2 Instrument Description - Multiple independent detector modules are mounted on a single structural frame with coincident main viewing directions. Typical dimensions for each detector module are shown in figure 1; these dimensions are tentative and could be modified if support requirements would be improved or simplified.

Each module consists of:

a. A fine-grid collimator system, to collimate the directions of sensitivity of the module.

b. A multiple-anode, ultra-thin-window, gas-filled proportional counter, to detect the soft X-ray component.

c. A dual-layer (phoswich) scintillation crystal array and detecting photomultiplier tubes, to detect the hard component X-rays.

d. A guard counter around the peripheral sides of the module, to detect photons entering through the side without passing through the collimator.

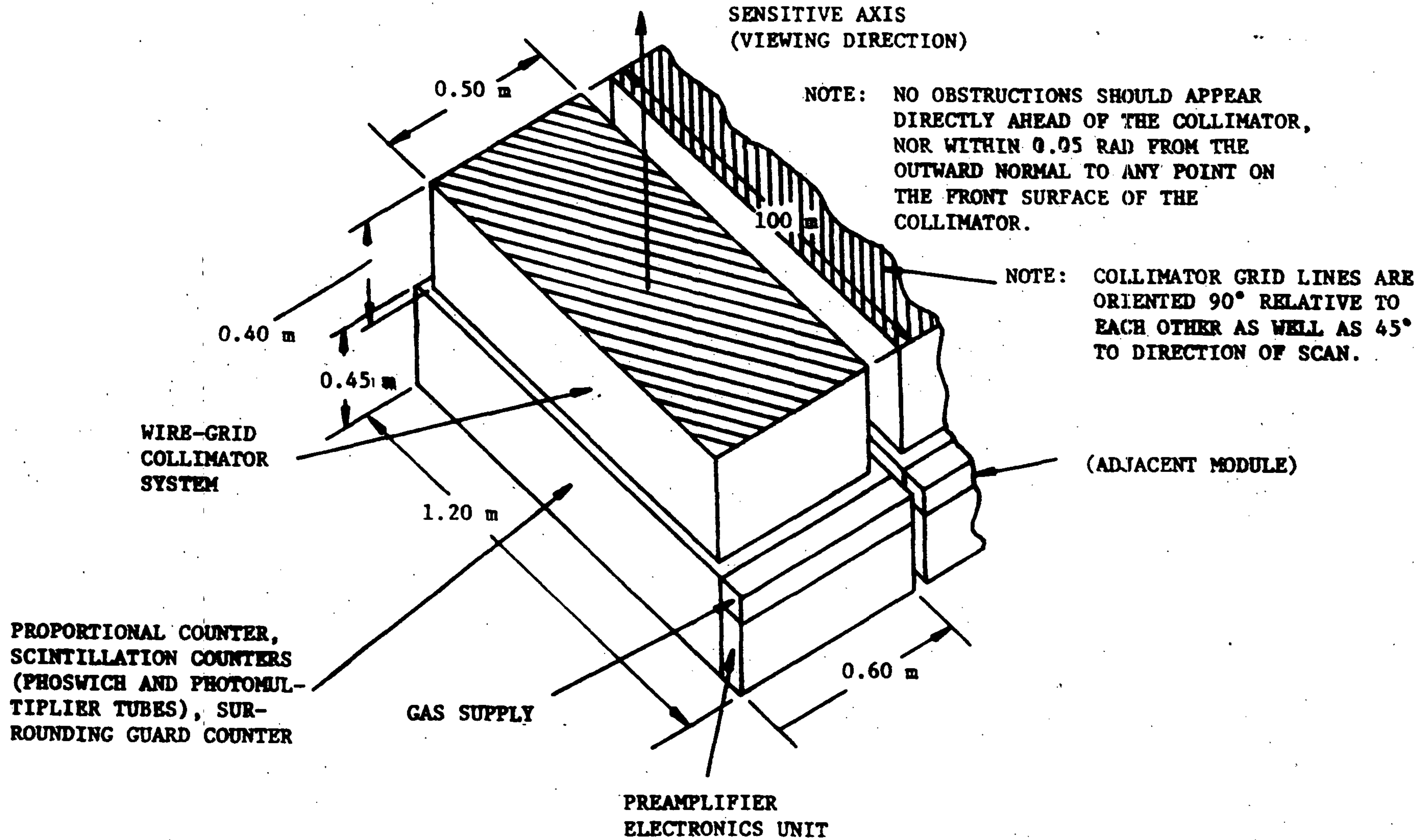

Figure 1. Typical Dimensions of Individual Module, Large Modulation Collimator

e. An electronics package to supply the required voltages for the detectors and perform the first level of signal amplification and processing.

f. A gas supply to replenish the proportional counter gas.

g. A star sensor that views the background star field through the same collimator system.

The collimator system consists of several layers of accurately-indexed, fine-wire grids, spaced to yield a transmission pattern as shown in figure 2 when measured in a plane perpendicular to the wires. In the orthogonal plane the transmission pattern has a single peak, made up of two ramps, equivalent to the envelope of the fine-grid pattern, with approximately 0.05 rad (3 degrees) full-width half-maximum sensitivity.

Figure 1 shows the wires oriented at +45° ($\pi/4$ rad) to the rectangular sides of the module. A pair of modules consists of one module as in figure 1, together with a similar module where the orientation of the wires if $-\pi/4$ (-45°) referred to the sides of the module. A complete instrument consists of three such pairs, i.e., six modules. Each pair has a specific characteristics spacing, δ. The three characteristic spacings are selected so as to eliminate possible ambiguities resulting from the multiple peaks of the collimator pattern as shown in figure 2.

The effective (X-ray-sensitive) capture area of each module with dimensions as shown in figure 1 is 0.25 m^2; a sensitive area of 1.5 m^2 is achieved by combining six modules. This total sensitive area would represent an instrument with excellent scientific and observational potential. If a greater total sensitive area can be accommodated, it should be considered in the program.

The instrument must be mounted on gimbals to provide freedom to orient the sensitive axis independent of the carrier vehicle's orientation constraints, to decouple the instrument from the Space Shuttle's angular drifts, and to allow oscillation of the experiment axis during the data acquisition periods.

To retain adequate transmission at the low energy range, the proportional counter windows must be extremely thin, and cannot be provided with thermal covers for protection. The instrument's axis must not be pointed closer than $\pi/4$ (45 degrees) to the sunline.

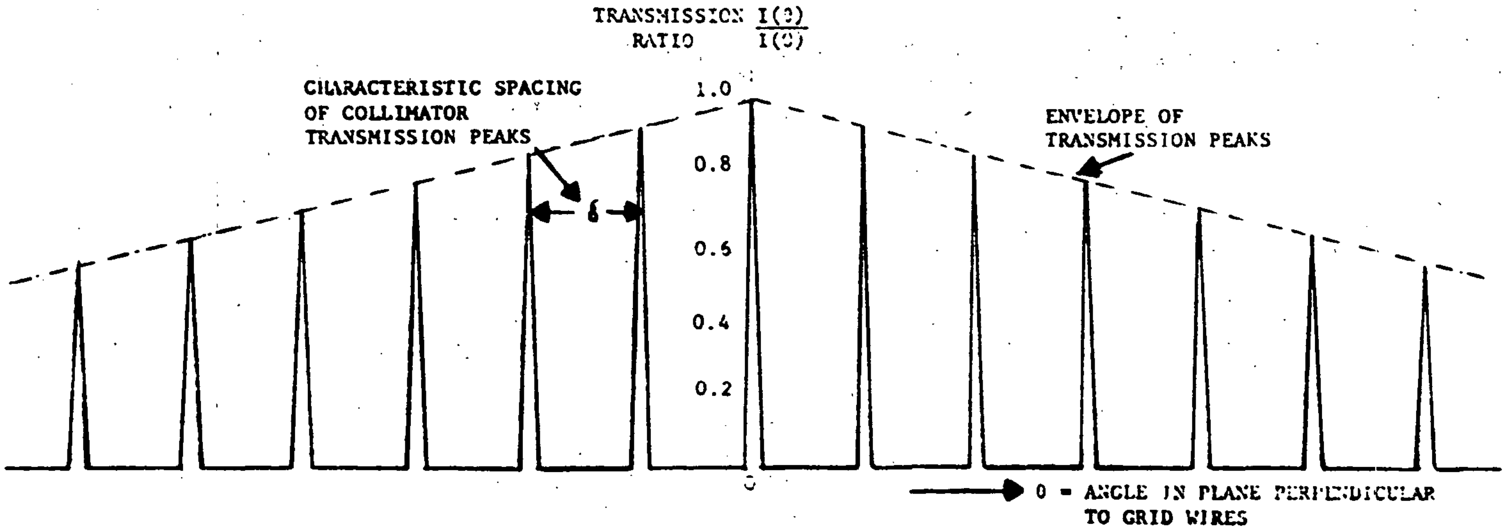

Figure 2. Angular Dependence of Transmission of Wire-Grid Collimator System

A central data processor is also required to format and buffer the data. Timing signals referenced to GMT are required at the processor, with maximum error of 1 msec.

2.3 Physical Configuration and Power Requirements - Descriptions of experiment and support equipment characteristics and mounting arrangements are given in the following sections. These requirements should be considered tentative, as the experiment design is in its preliminary stages. The instrument mounting arrangement is strictly conceptual; even a tentative detailed design does not exist yet. Nonetheless, the descriptions and physical characteristics are deemed sufficient for preliminary planning purposes.

2.3.1 Interface Block Diagram - The equipment interface diagram is shown in figure 3. This diagram identifies the major interfaces between the instrument and the spacecraft subsystems.

2.3.2 Scientific Equipment Characteristics - Preliminary scientific equipment characteristics are listed in Table I. (There is a possibility that sealed proportional counters will be used, in which case the gas supply is deleted).

2.3.3 Support Equipment Characteristics - Preliminary estimates of the support equipment required for this instrument are listed in Table II.

2.3.4 Instrument Mounting and Alignment Requirements - The proposed mounting arrangement for the six modulation collimator detector modules is shown in the sketch of Figure 4. The gas supply is best mounted on the support structure, either on the side, or on a bracket to locate it at the center of the array. The central data processor and the low voltage power supplies are best located on the support structure, even though this means a slightly larger gimbal. The high voltage power supplies are contained within the individual modulation collimator detector modules, as are the preamplifiers and certain pulse discrimination circuitry. The aspect sensors are located within the modulation collimator modules, and look through the collimator wire grids.

2.4 Operations - The participation of the crew in the functions associated with this instrument is briefly described chronologically in the following sections.

2.4.1 Functional Flow Diagram - A gross outline of the functions required is shown in Figure 5.

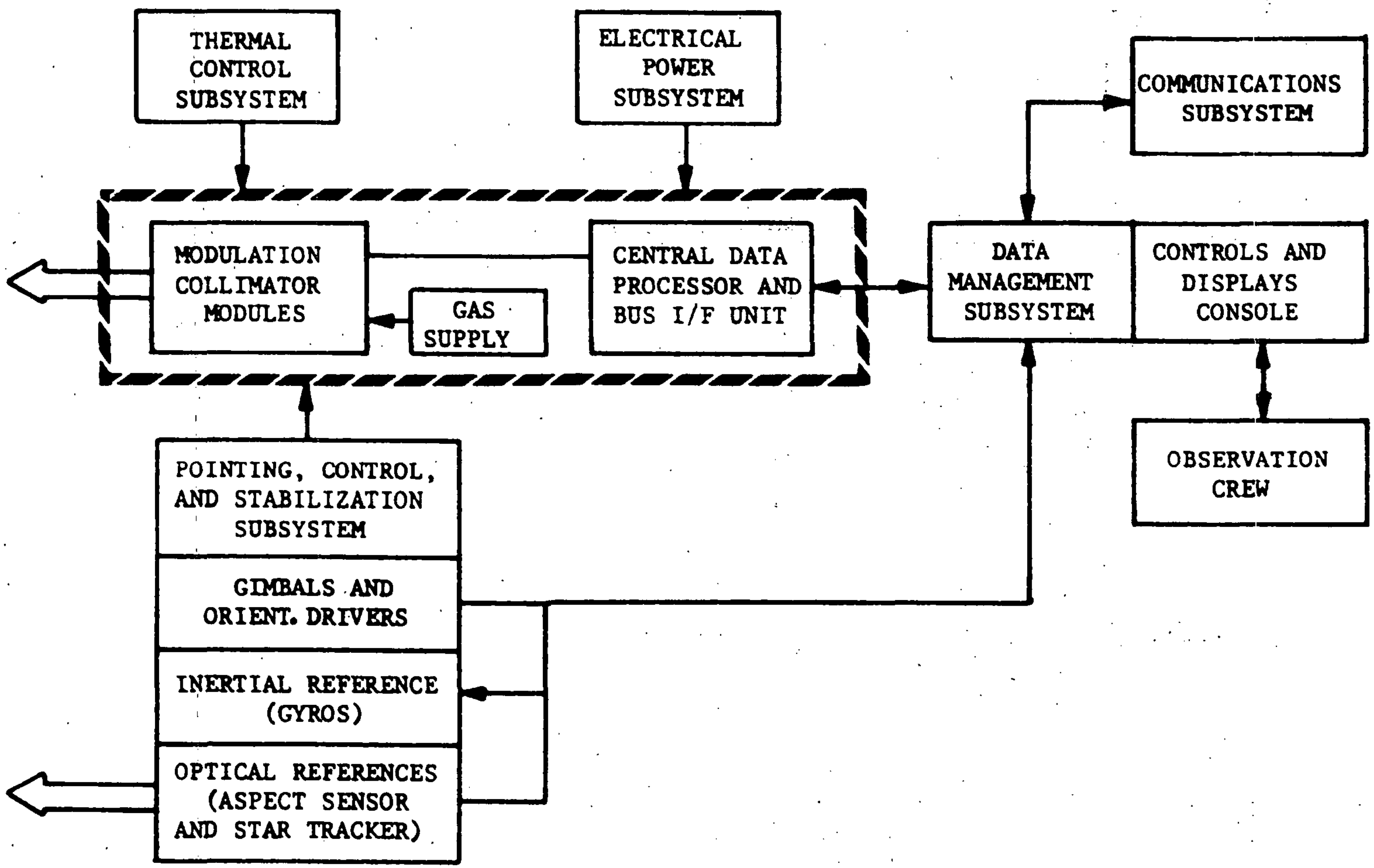

Figure 3. Interface Block Diagram

Table I. Experiment Equipment

DESCRIPTION	QTY	WIDTH	HEIGHT	LENGTH	DIAMETER	VOLUME	WEIGHT	DATA (bps)	POWER (watts)
DETECTOR MODULES	(6)	2.40 m	0.85 m	1.80 m	-	3.7 m^3	300 kg	HSKPG: 240	60
CENTRAL DATA PROCESSOR	1	0.30 m	0.30 m	0.90 m	-	0.08 m^3	25 kg	SCI: 4000 HSKPG: 50	40
SUPPORT STRUCTURE	1	2.90 m	-	2.30 m	-	-	~50 kg	-	-
GAS SUPPLY	1	-	-	-	0.1 m	0.0005 m^3	5 kg	HSKPG: 30	1 (20 watt peaks)
		VOLUME AND WEIGHT TOTAL (SI):				3.8 m^3	~375 kg		

Table II. *Support Equipment*

DESCRIPTION	QTY	WIDTH	HEIGHT	LENGTH	DIAMETER	VOLUME	WEIGHT	DATA (bps)	POWER (watts)
THERMAL CONTROL	1	TBD							20-100 w avg: 100
GIMBAL MOUNT (INCLUDING REFERENCE SYSTEMS; GYROS, ASPECT SENSOR, STAR TRACKER)	1	2.9 m	0.8 m	1.8 m		4.2 m^3 (enclosed)	200 kg	100 150 250 100	Δ = 200 pk 30
CONTROLS AND DISPLAY CONSOLE	1	0.3 m	1.3 m	1.0 m	-	0.39 m^3	200 kg	TBD	avg. 170 w

VALUES SHOWN ARE ENGINEERING ESTIMATES BASED ON CURRENT DESIGNS

VOLUME AND WEIGHT TOTAL (SI): ______ ______

VOLUME AND WEIGHT TOTAL (ENG): ______ ______

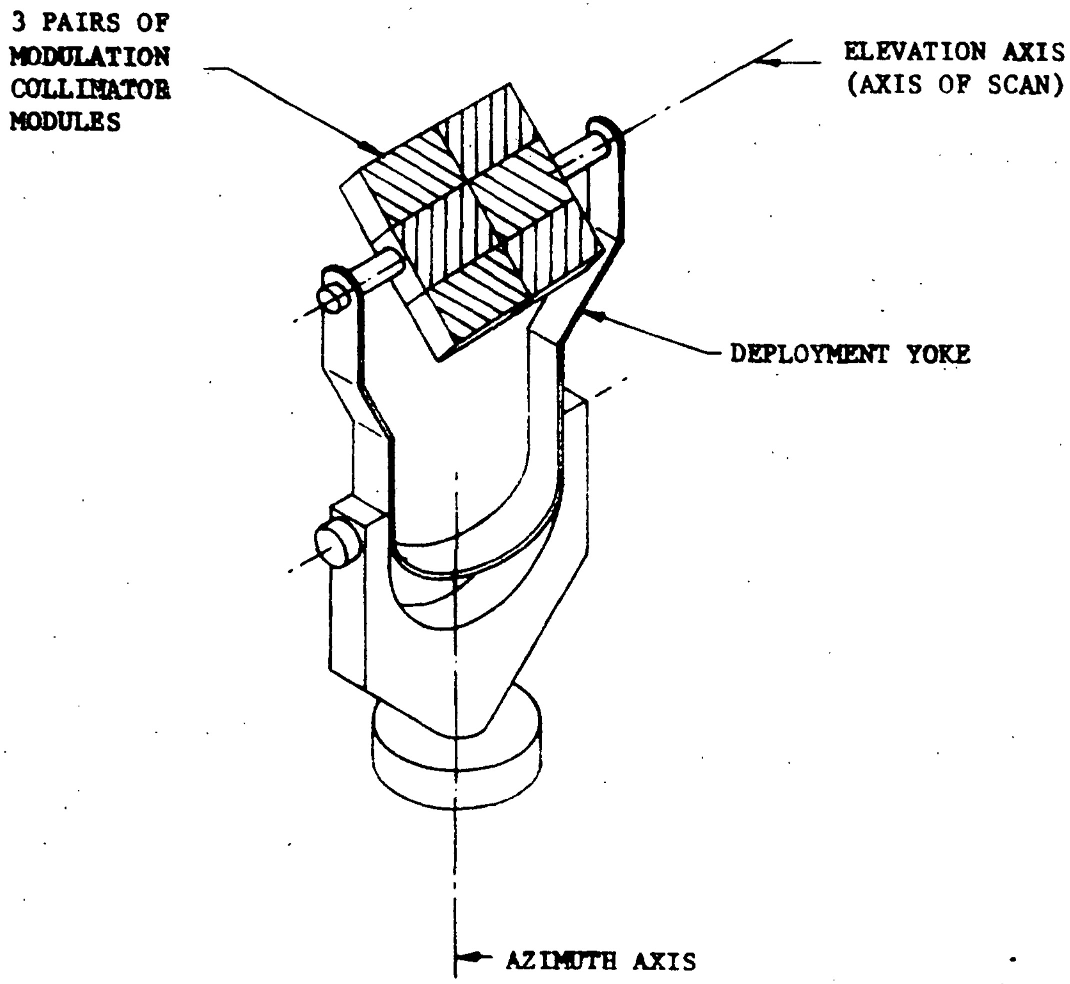

Figure 4. Possible Mounting Arrangement

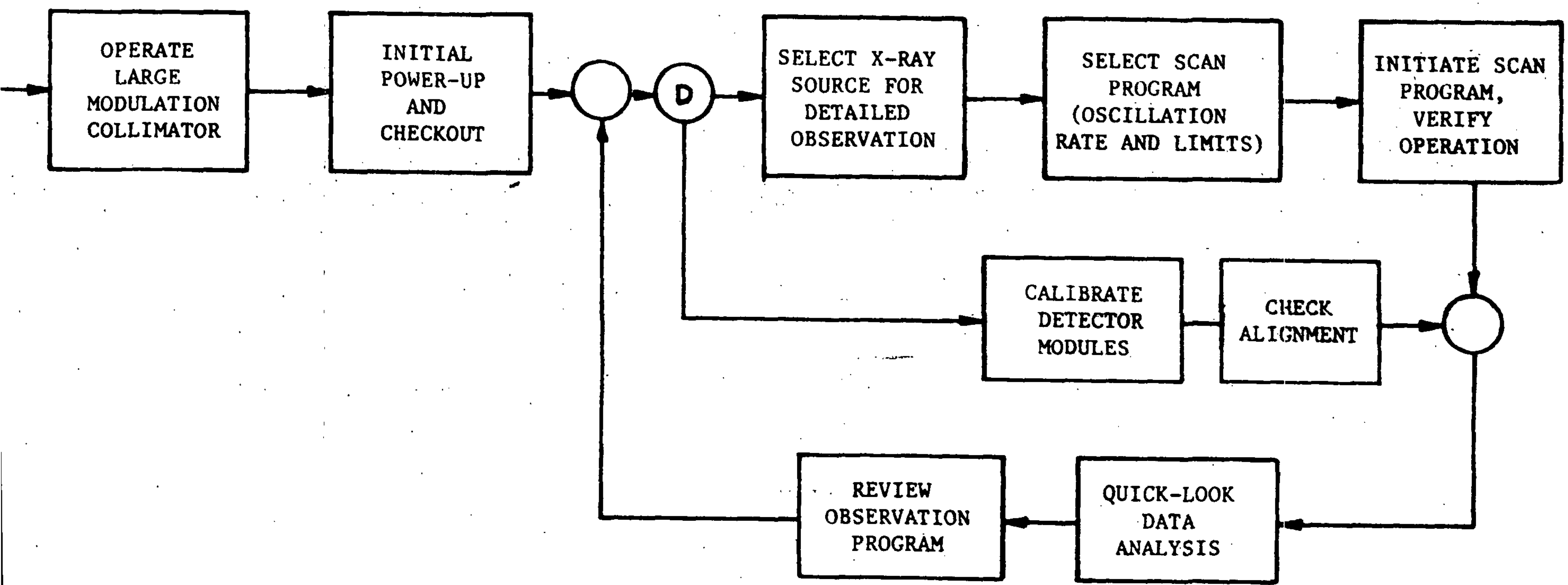

Figure 5. Functional Flow Diagram

2.4.2 Instrument Preparation Requirements - After the Shuttle has achieved stable orbit, and before any functions are performed with the experiment hardware, a visual safety check of the instrument is performed through the cabin window. All of the experiment hardware, with the exception of the control and display console (and possibly the central data processor), is located outside of the pressurized cabin.

Electrical power to the instrument is turned on, specifically power to the thermal control, gimbals, and central data processor, and the low voltage power supplies. Approximately 3 hours should be allowed for warm-up and attainment of thermal equilibrium. Operation of these subsystems is check out. Alternate low voltage power supplies are placed into operation if necessary, and all voltages are adjusted to nominal values. Using simulated signals, operation of the central data processor is verified.

Purging and refilling of the gas proportional counters which constitute the detectors is not expected to be required initially. Pressure in the individual detector modules is checked at this time.

The launch restraints are released, and the operation and travel of the gimbal system is verified. Operation of the oscillating motion required for target scanning is also verified.

The high voltage power supplies are turned on and applied to the proportional counters, individually, one by one, and operation of each counter is verified. Alternate power supplies and preamplifiers are selected if required. Operation of the aspect sensor/star tracker is likewise verified at this time. During this portion of the checkout, it may be desireable to point the instrument at some prominent stellar source. Prior to checkout on X-ray sources, however, calibration should be performed.

Calibration is accomplished by inserting radioactive sources into the counter, and noting the output of the pulse height analyzers. A calibration source will be provided for each pair of counters. Adjustments to the high voltage, and to pulse discriminator settings are then made as required.

Celestial orientation references are now established. The Shuttle orientation data are combined with the gimbal angles to define the gimbal coordinates for acquiring a selected celestial reference X-ray source. Manual acquisition and tracking of the source is performed by orienting the entire instrument, then introducing the computed offset angles to the star tracker, so that

the latter can acquire the selected pointing star. Following verification of acquisition, manual tracking and then automatic tracking is initiated.

Misalignment will become evident at this time, Alignment should first be checked between the three pairs of modulation collimators as the entire instrument scans across the reference source. Appropriate corrections to the alignment are entered into the central data processor. (It is anticipated that misalignment may be corrected by entering in compensating delays in the individual pulse processing circuitry). With alignment corrections made to the assembly of six modulation collimators modules, alignment between the aspect sensor/star tracker and the modulation collimator arrays is then determined, and necessary corrections noted for future determinations of offset angle.

2.4.3 <u>Instrument Operation Requirements</u> - The generic name "modulation collimator" derives from the use of the transmission pattern shown in figure 2 to scan the region of the source. For a point source, if the collimator is rotating at a uniform rate about the axis of the grid wires, the count rate measured as a function of time is as shown in figure 2: now you see it, now you don't, now you see it again, etc. The accuracy of the instrument is obtained by the careful analysis of the modulation produced by angular motion of the collimator. Therefore, it is required that the collimator orientation be oscillated over the region of the source of interest.

To simplify the operational procedures, the collimator modules are arranged in pairs, as described in paragraph 2.2 above. In this manner, when the collimators are rotated about either of the principal rectangular axes (normal to the viewing direction) the rotation causes modulation in <u>both</u> collimators, providing independent analyses of the source in two orthogonal directions at once. It is not always trivial to combine these two independent one-dimensional analyses, particularly if the source has a highly complex structure, but it is always feasible.

The functional flow diagram, figure 5, shows the basic operations to be performed. After the initial operations and detector module calibrations are complete, a review is performed of the sources with high observational priority to determine which of these can be observed with the current spacecraft orientation. One of these X-ray sources is selected for observation. The limits of the oscillating scan are selected to insure full coverage of the source, and instrument operation is initiated. The output from the detector modules is observed at the controls and

displays console by the crew to verify proper operation; the instrument continues to acquire data from the source for up to 2400 seconds (40 minutes) when a different X-ray source is selected for observation.

Fourty minutes is the time available for a single source in a single orbit. Dim sources may require more observation time for signal integration. It is envisioned that a total of 300 minutes may be used for a source. In this case, other sources may be observed also during that portion of the orbit when the dim source is eclipsed by the earth. This sort of program is not reflected in the timeline shown in Table III.

2.4.4 Instrument Post-Operation Requirements - The major post-operation functions are as follows:

a. Orient the modulation collimator array to launch position, and reset the launch restraints.

b. Turn off the high voltage power supplies.

c. Set the gas vent and supply valves in re-entry configuration. (Depending on hardware design, this may be fully automatic).

d. Turn off all remaining electrical power to the experiment.

All operations are performed through the Control and Display console; EVA is not normally required.

2.4.5 Typical Operational Timeline - Table III shows a typical timeline for operation of the Large Modulation Collimator.

2.5 Environmental Requirements/Constraints - The environmental characteristics which must be provided for the Large Modulation Collimator are shown in Table IV.

2.6 Data - The primary scientific data is described in Table V, together with auxiliary data required. The auxiliary data includes instrument housekeeping; data from the aspect sensor/star tracker, rate gyros, gimbal encoders, and spacecraft IMU unit; timing signals which can be correlated with GMT with an accuracy of 0.1 millisecond. Voice comments by the crew are also included. This complete data package represents the basic information which will be used to achieve the scientific objectives of the experiment.

Table III. Typical Operational Timelines
(Modulation Collimator)

INITIAL

SUPPORT REQUIREMENTS / EXPERIMENT OPERATING SEQUENCE	SAFETY CHECK	ELECTRICAL POWER ON	WARM-UP; SYSTEM CHECKOUT	VERIFY DATA PROCESSOR	PURGE, REFILL PROP. COUNTERS	DETECTOR H.V. ON	DETECTOR CHECK	CALIBRATION	RELEASE LAUNCH RESTRAINTS	GIMBAL FUNCTIONAL CHECK	STAR SENSOR ORIENTATION	GYRO REFERENCES	ALIGNMENT CHECK
TIME (MINUTES)	5	1	180	20	(300)	1	14	30	5	15	5	2	30
CREW	X	X	X	X	X	X	X	X	X	X	X	X	X
SCIENTIFIC EQUIPMENT: DETECTOR MODULES	X	X	X	X	(X)	X	X	X	*	*	*	*	X
SCIENTIFIC EQUIPMENT: DATA PROCESSOR	X	X	X	X	*	X	X	X	*	*	X	X	X
SCIENTIFIC EQUIPMENT: SUPPORT STRUCTURE (incl. Thermal)	X	X	X	X	X	X	X	X	X	X	X	X	X
SCIENTIFIC EQUIPMENT: GAS SUPPLY	X	X	X	*	X								
SUPPORT EQUIPMENT: GIMBAL MOUNT	X	X	X	*	*	*	*	*	X	X	X	X	X
SUPPORT EQUIPMENT: ASPECT SENSOR/STAR TRACKER	X	X	X	*	*	*	*	*	*	*	X	X	X
SUPPORT EQUIPMENT: GYROS	X	X	X	*	*	*	*	*	X	X	X	X	X
SUPPORT EQUIPMENT: CONTROL/DISPLAY CONSOLE	X	X	X	X	X	X	X	X	X	X	X	X	X

REPEATED

SUPPORT REQUIREMENTS / EXPERIMENT OPERATING SEQUENCE	SELECT TARGET	ORIENT (SLEW) DETECTOR	ACQUIRE TARGET	DATA ACQUISITION	QUICK-LOOK DATA ANALYSIS	OBSERVATION PROGRAM REVIEW
TIME (MINUTES)	2	5	3	20 to 300	(20)	(20)
CREW	X	X	X	(X)	X	X
SCIENTIFIC EQUIPMENT: DETECTOR MODULES	*	*	X	X	*	*
SCIENTIFIC EQUIPMENT: DATA PROCESSOR	*	*	X	X	X	X
SCIENTIFIC EQUIPMENT: SUPPORT STRUCTURE (incl. Thermal)	X	X	X	X	*	*
SCIENTIFIC EQUIPMENT: GAS SUPPLY						
SUPPORT EQUIPMENT: GIMBAL MOUNT	*	X	X	X	X	*
SUPPORT EQUIPMENT: ASPECT SENSOR/STAR TRACKER	X	X	X	X	X	*
SUPPORT EQUIPMENT: GYROS	X	X	X	X	X	X
SUPPORT EQUIPMENT: CONTROL/DISPLAY CONSOLE	X	X	X	X	X	X

OCCASIONAL

SUPPORT REQUIREMENTS / EXPERIMENT OPERATING SEQUENCE	DETECTOR HV POWER OFF	PURGE/REFILL DETECTORS	DETECTOR HV ON; CHECK	CALIBRATION	ALIGNMENT CHECK
TIME (MINUTES)	1	(300)	15	30	30
CREW	X	X	X	X	X
SCIENTIFIC EQUIPMENT: DETECTOR MODULES	X	(X)	X	X	X
SCIENTIFIC EQUIPMENT: DATA PROCESSOR	*	*	X	X	X
SCIENTIFIC EQUIPMENT: SUPPORT STRUCTURE (incl. Thermal)	X	X	X	X	X
SCIENTIFIC EQUIPMENT: GAS SUPPLY		X			
SUPPORT EQUIPMENT: GIMBAL MOUNT					X
SUPPORT EQUIPMENT: ASPECT SENSOR/STAR TRACKER					X
SUPPORT EQUIPMENT: GYROS	*	*	*	*	X
SUPPORT EQUIPMENT: CONTROL/DISPLAY CONSOLE	X	X	X	X	X

FINAL

SUPPORT REQUIREMENTS / EXPERIMENT OPERATING SEQUENCE	DETECTOR HV OFF	VENT DETECTORS	GIMBALS TO LAUNCH POSITION RESET LAUNCH RESTRAINTS	ELECTRICAL POWER OFF
TIME (MINUTES)	1	(300)	2	1
CREW	X	X	X	X
SCIENTIFIC EQUIPMENT: DETECTOR MODULES	X	X		
SCIENTIFIC EQUIPMENT: DATA PROCESSOR	*			
SCIENTIFIC EQUIPMENT: SUPPORT STRUCTURE (incl. Thermal)	X	X	X	
SCIENTIFIC EQUIPMENT: GAS SUPPLY		X		
SUPPORT EQUIPMENT: GIMBAL MOUNT	*	*	X	
SUPPORT EQUIPMENT: ASPECT SENSOR/STAR TRACKER	X			
SUPPORT EQUIPMENT: GYROS	*	*	X	
SUPPORT EQUIPMENT: CONTROL/DISPLAY CONSOLE	X	X	X	X

* EQUIPMENT NOT SPECIFICALLY REQUIRED, BUT REMAINS TURNED ON AND DRAWING POWER
( ) VALUES ENCLOSED IN PARENTHESES MAY NOT BE REQUIRED

Table IV. Environmental Requirements/Constraints

		OPERATING	NONOPERATING
MECHANICAL	Acceleration Vibration Acoustic	Instrument is not susceptible to sustained acceleration; certain vibration frequencies may cause resonances in counters and collimators.	Withstands normal launch and re-entry environments without damage.
THERMAL	Absolute temperature limits	291 to 295 K	263 to 303 K
	Differential temperature limits	1 1/2 degrees K between collimator frames	1 1/2° K between collimator frames
ATMOSPHERE	Pressure	$<10^{-5}$ Torr	N/A
	Humidity	N/A	Less than 40% R.H.
	Contaminants	Moderate sensitivity. Thin windows may be sensitive to RCS effluent.	100,000 class clean room specifications.
EXTERNAL INTERFERENCES	Magnetic fields	0.2 millitesla (2 gauss) at photomultipliers.	Not critical
	RF fields	TBD (See Note below)	TBD (See Note below)
	Ionizing background	Sensitive to South Atlantic Anomaly flux; will require power-down during SAA crossings. Background should be less than $10^{-7} cm^{-2} sec^{-1}$.	Crossings through SAA must not generate radioactivity in instrument or surrounding structures.

NOTE: The RF field susceptibility of the proportional counter detectors is primarily determined by the shielding and isolation that is provided for in the design. The detector modules are still in the conceptual design stage. While detectors of similar design have been successfully flown on rocket flights and the Small Astronomy Satellite, these detectors were far smaller in physical size and sensitivity than the detectors described herein. Susceptibility to EMI therefore is TBD.

Table V. Recorded Data Requirements

CLASS	DESCRIPTION	FORMAT	READOUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION
Scientific	Coded digital word; pulse height amplitude time, collimator group	digital 10-bit	100 sec^{-1}	1000 bps	Continuous	500 Mbits	1:1
	Count rate monitors, commutated 8 units	digital 10-bit	1 sec^{-1}	80 bps	Continuous	40 Mbits	1:10
Instrument Housekeeping	Voltage, temperature pressure, 50 points commutated	digital 10-bit	0.10 sec^{-1}	50 bps	Continuous	25 Mbits	1:10
	Status monitors 40 words	1 bit words	1 sec^{-1}	40 bps	Continuous	20 Mbits	1:1
Crew's Annotation	Voice comments Logbook entries	analog written	as required	3 KHz	Continuous	120 to 140 hrs.	-
SUBSYSTEM							
Spacecraft Attitude Angles	IMU signals	digital 3x15 bit	0.01 sec^{-1}	0.45 bps	Continuous	0.27 Mbits	1:1
Gimbal Angles	Angle encoders	digital 2x15 bit	0.05 sec^{-1}	1.5 bps	Continuous	0.75 Mbits	1:1
Rocking Gimbal Angle	Angle encoder	digital 1x20 bit	1 sec^{-1}	20 bps	Continuous	10.0 Mbits	1:40
Star Tracker/ Aspect Sensor	Offset angles	digital 2x8 bit	0.05 sec^{-1}	0.8 bps	Continuous	0.4 Mbits	1:1
	Sensed error angles	digital 2x4 bit	0.10 sec^{-1}	0.8 bps	Continuous	0.4 Mbits	1:1
Rate Gyros	Angular rates	digital 2x10 bit	10 sec^{-1}	200 bps	Continuous	100 Mbits	1:4
Timing	Clock reference	digital 24 bit	1 sec^{-1}	24 bps	Continuous	12.0 Mbits	1:1

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In addition to the recording of data, it must be available for real-time monitoring at the Control and Displays Console, as defined in Section 2.8. All commands to the scientific and support equipment will be performed by the crew through the Control and Display Console. In-flight support from ground-based personnel will take the form of verbal communications with the crew via the voice communications link.

2.7 <u>Pointing</u> - The required accuracy of pointing to a source of interest is ± 0.009 radians ($\pm 1/2$ degree) about the two axes orthogonal to the field-of-view centerline. Recall the overall field-of-view of the modulation collimator is approximately 6 degrees. The modulation collimator can operate only by scanning across the source of interest orthogonal to the field-of-view centerline, and 45 degrees to each of the collimator grid directions. It is assumed that the scan will be an oscillation motion of the inner gimbal over a range of ± 0.09 radians (or ± 5 degrees). The modulation collimator array should be pointed at the target so the target is positioned in the center of the scan.

The stability of the pointing and the scan should be sufficient to enable superposition of two succeeding scans to an accuracy of 0.000025 radians (5 arc seconds). A period of oscillation of 18 seconds yields an angular scan rate of 0.01 rad/sec, equivalent to that experienced by the modulation collimator experiment in HEAO-A. A stability of 25 microradians (5 arc seconds) in 18 seconds time is equivalent to a rate of about 0.003 radians/hour (0.15°/hr). This is a reasonable requirement compared to the pointing accuracy required.

The requirements for angular acceleration derived for HEAO-A is on the order of 25 microradians per second^2, which is a reasonable requirement for a uniformly rotating spacecraft. It is obviously incompatible with the scanning motion produced by an oscillating gimbal. For this reason, it will be probably necessary to read out gimbal coordinates to an accuracy of 25 microradians or better at a sampling rate of about 10 samples per second. The rate gyros will be needed to extrapolate angular position data between gimbal coordinate readouts. The ultimate accuracy, comes from this extrapolation. A timing signal precision of 100 microseconds is required.

In order to be able to survey the entire sky, it is necessary to mount the modulation collimator array on a gimbal system which can provide roughly hemispherical orientation freedom for the field-of-view of the experiment. To make good use of available observing time, it is desireable to observe two separate sources of interest per orbit, with these sources of interest located roughly 120 to

180 degrees apart. Therefore the gimbals must be capable of orienting the instrument from one source to another with slewing rates of at least 0.05 radians/sec (3 degrees/sec), about both axes.

2.8 Controls and Displays - The functional requirements for the controls and displays required to operate the instrument are listed in Tables VI and VII. Table VI lists the requirements for the scientific equipment, and Table VII lists the requirements for the support equipment.

2.9 Preflight/Postflight Ground Support - The ground support requirements are briefly described in this section. Major equipment and facilities are listed, and the principal features of the test and calibration program are stated.

2.9.1 Ground Support Equipment and Facilities - The major facility and equipment requirements are listed in Table VIII.

2.9.2 Test, Checkout and Calibration - After instrument installation is completed according to the established interface requirements, test and checkout of the complete experiment system will be executed. While a detailed procedure for test, checkout, and calibration is not defineable at this time, the major operations that will be required is outlined below:

a. Checkout of all power supplies.

b. Checkout of the discriminators and pulse height analyzers using simulated signals.

c. Signal test of each module with true X-ray photon flux into the detectors, monitored at the data recording point. Filling of the proportional counters with gas is required, and data interpretation will have to account for a different pressure or gas than is used in orbit.

d. Checkout of the aspect sensor and star tracker, with images displayed at the Control and Displays Console.

e. Final alignment verification among the six modulation collimator modules, and the aspect sensor/star tracker.

f. Operational verification of the gimbal system for slewing rates, pointing accuracies, and alignment.

Table VI. Scientific Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
Main Power	ON/OFF	Indicator light
HV Power	ON/OFF (6)	Indicators (6)
Thermal Control	ON/OFF Adjust temperature (4) Meter selector	Analog meter
Main Gas Valve	Open/Close	Indicator light
Gas Transfusion	Operate	Indicator light
Gas Pressure	Selector switch	Digital meter
Calibration Rods	In/Out (3)	Indicators (3)
Operating Mode	Switches (4)	Lighted panels (4)
Counting Rate	ON/OFF Selector switch (8)	Digital meter
X-Ray Spectrum (Pha)	ON/OFF	Analog CRT
Detector Module Select	Selector switch (7)	Lighted panel
Discriminator Threshold	Raise/Lower	Digital meter

Table VII. Support Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
Gimbal System:		
Main Power	ON/OFF	Indicator light
Primary Instrumentation	ON/OFF	Indicator light
Shuttle Celestial Orientation	-	Digital (2)
Gimbal Angles	Plus/Minus (2)	Digital (2)
Oscillating Gimbal	ON/OFF/Reset	Analog
Field of View Orientation	-	Digital (2)
Source Map	ON/OFF, Index	Projected slides
Target Coordinates Commanded	Number keyboard	Digital (2)
Star Sensor Field	ON/OFF Threshold adjust	CRT
Star Sensor Offset	Plus/Minus (2)	Digital (2)
Star Sensor Lock On	ON/OFF	Indicator

Table VIII. Ground Support Requirements

EQUIPMENT	Controlled Environment Storage Container Handling/Installation Fixture Module Alighment Fixture, with alignment telescopes Calibrated X-Ray Sources Checkout/Calibration Monitor System
FACILITIES	Proportional Counter Gas Supply Clean Room (100 000-class low humidity) Prelaunch Environment Control Facility

g. Calibration of the proportional counter characteristics prior to launch. The calibration is to be repeated after the experiment is returned from orbit.

2.9.3 Accessibility Requirements - Following prelaunch checkout and calibration, access may be required to replace or renew the high-pressure gas reservoirs. However, if the instrument is subjected to environments outside limitations specified in Table IV, access may be required.

2.10 Post Mission Refurbishment - After completion of a mission in which successful observations were performed, the refurbishing services expected to be performed are:

a. Flushing and replenishment of the gas mixture in the proportional counters;

b. Realignment or replacement of the wire grids in the modulation collimators. (The wire grids are somewhat delicate, and require precise alignment of 5 arc seconds (25 microradians), and 8 micron relative displacement (0.0003 inch).

c. Occasional replacement of preamplifiers, and photomultipliers. (These may become insensitive and noisy after sufficient exposure to the radiation in space).

2.11 Orbital Parameters - The scientific equipment is compatible with all orbits which have been suggested for the Shuttle. The influence of orbital altitude and inclination are:

a. Altitude and inclination change the expected minimum ionized particle background flux in a complex manner. Roughly, over the range of altitudes and inclinations considered, background radiation increases with both increased altitude and inclination. Special attention must be given to the portion of the orbit occupied by the South Atlantic Anomaly, when no data can be taken.

b. Viewing capability of specific sources may increase with greater altitude and higher inclination, because of less obscuration of the earth.

c. Lower altitudes significantly increase absorption cross-section of the residual atmosphere, complicating interpretation of data.

3. PROGRAMMATICS

Equipment Costs and Scheduling, Safety Considerations, and Reliability are the topics included in this section. Because the experimental hardware is not defined in detail, equipment costs and scheduling and reliability are necessarily rough estimates. The basis for these estimates is similar hardware now in the design stage for HEAO-A. Safety considerations are based upon a cursory analysis of the experiment as originally proposed. The statements made must be regarded as highly tentative, yet they are the best available until an Experiment Definition Study is accomplished.

3.1 Equipment Cost and Schedule - The only basis for cost estimates are cost goals currently stipulated for the Modulation Collimator experiment on HEAO-A, which is about $7.5 million, and the cost estimate for LAXRAY, which is $7.8 million. The experiment described herein is rather larger physically than the experiment but with modulation collimators which are arrays of wire grids, instead of the "egg-crate" collimators used for LAXRAY. The Large Modulation Collimator therefore should require slightly more time and cost to develop than the LAXRAY for ASM. Inasmuch as both LAXRAY and a Modulation Collimator experiment are being developed for HEAO-A, and this development will precede that for similar experiments on the ASM, laboratory units (brass-board) are not considered necessary. Development should be able to proceed directly to space-hardened units. A series of possible estimates are shown in Table IX.

3.2 Safety Considerations - All scientific equipment and support equipment with the exception of the Control and Displays console and perhaps some data processing circuitry are located in the shuttle bay, outside the crew compartment. There are no pyrotechnic or explosive devices required, but the high-pressure gas reservoirs represent a possible hazard.

The gas reservoirs will be mounted with the modulation collimator detectors on the gimbals. The amount of gas is sufficiently small that if a rupture should occur, there will not be a significant pressure buildup in the shuttle bay. The crew compartment wall probably will give sufficient protection to the crew from flying debris. The crew compartment wall should be designed to withstand flying fragments from a 3000 psi ruptured pressure vessel at a distance of about 15 feet. The gas mixture planned for use is argon/carbon dioxide, which is not flammable.

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)	(0.2)	(1.20)	(2.10)	(2.15)	(1.30)			$ 6.95
PRODUCTION-FIRST ARTICLE			(1.00)	(1.50)	(2.03)	(0.65)		5.18
								$ 12.13

TABLE IX - SCHEDULE AND COST ESTIMATES, LARGE MODULATION COLLIMATOR

Table X. Mean-Time-Between Failure Estimates

UNIT \ LEVEL	SPACE HARDENED	SPACE QUALIFIED
Detector Modules	8,000 Hrs.	12,000 Hrs.
Central Data Processor	10,000	10,000
Mounting Frame	10,000	20,000
Gas Supply	5,000	8,000

NOTE: Gas supply reservoirs should be designed for a probability of rupture of 10^{-5} during any one mission.

Another possible hazard is failure of the launch restraints to engage prior to re-entry, or accidental release of the restraints. Without launch restraints, the instrument might break loose and cause severe damage to the Shuttle during high deceleration. Warning systems should be incorporated to indicate insecure launch restraints to the crew. However, failure of the launch restraints is regarded as highly unlikely, especially as it is expected that the launch restraints will be fabricated with a high degree of reliability.

3.3 Reliability - Equipment reliability depends primarily on the level of effort devoted to this subject during the design, development and fabrication phases of the equipment. The reliability incorporated into the design depends upon the goals established. Present planning for an ASM experiment requires from 2 to 7 flights, of 7 days duration each. Similar experimental hardware designed for HEAO are to be designed for 2 years operation (approximately 20,000 hrs.).

Probable mean-time-between-failure estimates are given in Table X, for the two types of cost estimates associated with Table IX.

4. NOTES

4.1 Bibliography - This report contains information obtained from the following documents. The documents are not referred to in the text.

a. Reference Earth Orbital Research and Applications Investigations, (Blue Book), Volume II, Astronomy, January 15, 1971.

b. A Proposal to Fly Large Area X-Ray Counters and Associated Hardware Aboard the HEAO, Naval Research Laboratory, Washington, D.C., Report No. P9-70. May 28, 1970.

c. Technical Proposal for a Scanning X-Ray Modulation Collimator Experiment for the High Energy Astronomy Observatory (HEAO-A), American Science and Engineering, Cambridge, Mass. Report AS&E 2407-11.

4.2 Abbreviations

aJ	atto-Joule
ASMDS	Astronomy Sortie Missions Definition Study
cm	centimeter
bps	bits per second

fJ	femto-Joule
GMT	Greenwich Mean Time
I/F	Interface Unit
K	degree Kelvin
keV	kiloelectron volts
m	meter
msec	millisecond
ORIENT	Orientation
PC	Proportional Counter
PHA	Pulse Height Analyzer
PMT	Photomultiplier Tube
rad	radian
sec	second
sec	arc-second
sr	steradian
TBD	To Be Determined
W	watt

2.10 COLLIMATED PLANE CRYSTAL SPECTROMETER

ASM-EXP-204-6
February 25, 1972

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

Baseline Experiment Definition Document (BEDD): ASMDS Collimated Plane Crystal Spectrometer

Contract GC1-115076

Prepared by:

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Approved by:

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Project Manager

The Bendix Corporation
Navigation & Control Division
Denver Facility
Denver, Colorado

CONTENTS

Figure

CONTENTS (Concluded)

1. INTRODUCTION

The purpose of this document is to define a baseline Collimated Plane Crystal Spectrometer experiment for the Astronomy Sortie Missions Definition Study (ASMDS).

The scientific objectives, configurations, operational requirements, environmental requirements, data, pointing, and controls and displays requirements, estimated ground support equipment and post-mission refurbishment requirements are identified.

2. DISCUSSION

2.1 Scientific Objectives - The objective of this instrument is to obtain high resolution spectral information on known celestial X-ray sources in the 0.08 to 1.6 fJ (0.5 to 10 keV) energy range. Both point sources and extended sources will be observed.

2.2 Instrument Description - The primary detector system consists of three Bragg crystal plates and gas proportional counters, each optimized for a specific energy range. A drive system allows the crystal plates to select any desired wavelength or scan a portion of the spectrum. The intensity of the X rays diffracted by the crystals as a function of angle is detected by proportional-counter/pulse-height-analyzer systems.

A gimballed mount is required to point and stabilize the instrument with respect to selected X-ray sources.

An aspect system is required to determine the orientation of the instrument within 0.0003 rad (1 arc minute). The aspect signals will also be processed in real time by the electronic equipment and used to correct the crystal angle directly for spacecraft drift and jitter.

An in-flight calibration system is an integral part of each spectrometer.

An outline drawing of the spectrometer assembly is shown in figure 1.

2.3 Instrument Interfaces and Characteristics - The interfaces with subsystems and physical characteristics of the scientific and support equipment are described.

2.3.1 Equipment Interface Diagram - The basic interface diagram is shown in figure 2. Only one of the detector units is shown for simplicity of presentation.

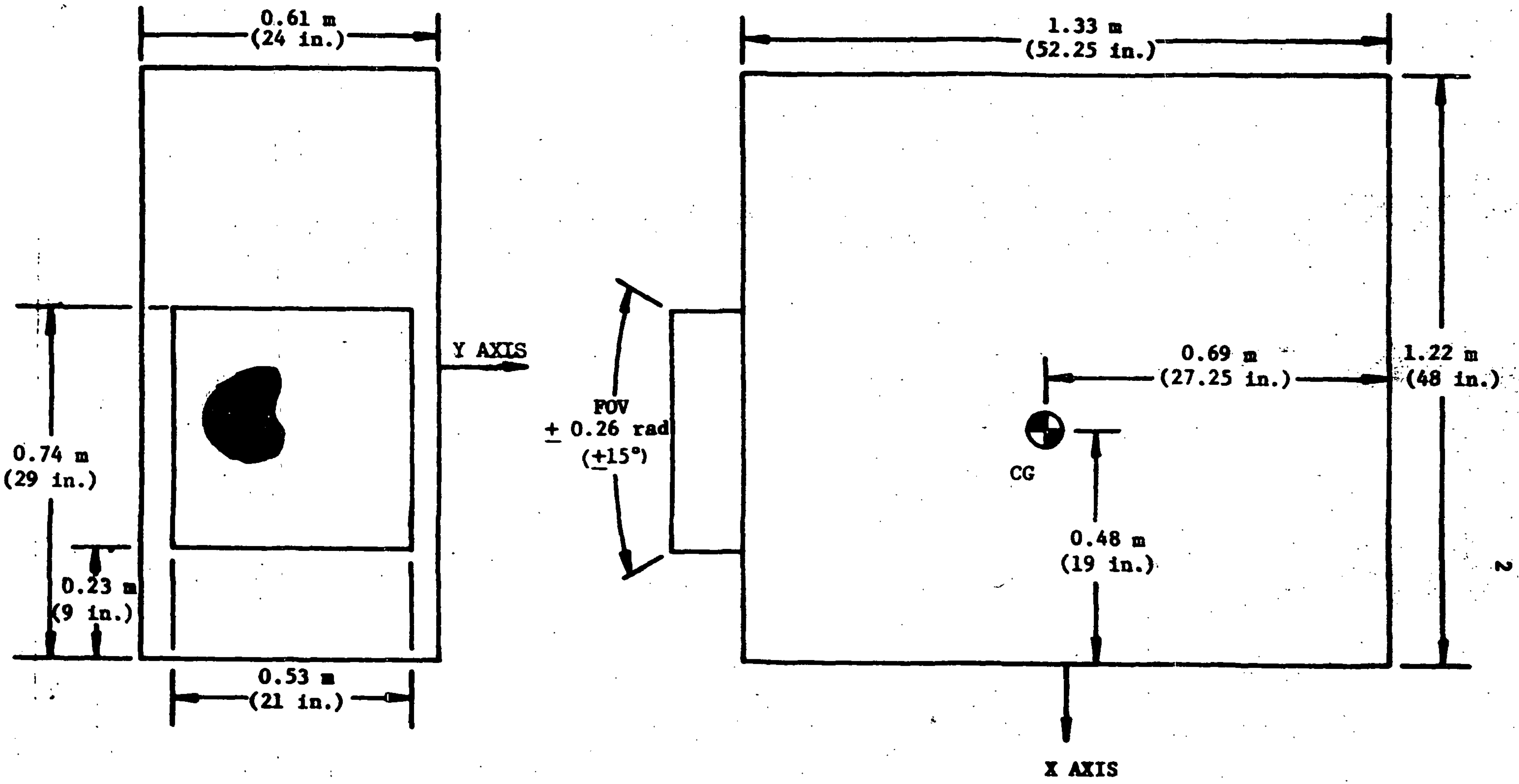


Figure 1. Collimated Plane Crystal Spectrometer: Outline Drawing, One Module

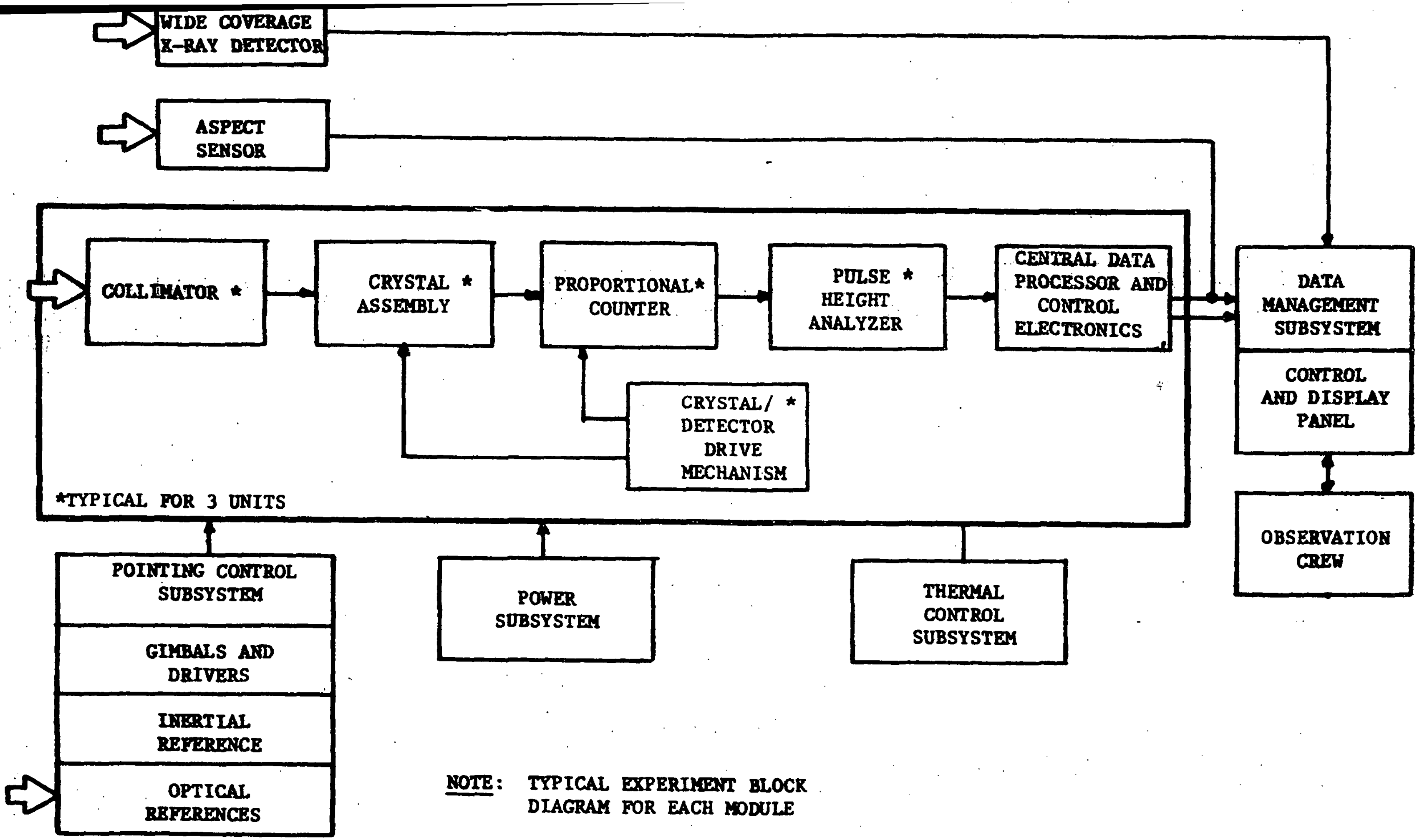


Figure 2. Collimated Plane Crystal Spectrometer: Interface Block Diagram

2.3.2 Scientific Equipment Characteristics - The physical characteristics and power requirements of the scientific equipment are listed in table I.

2.3.3 Support Equipment Characteristics - The physical characteristics and power requirements of the support equipment are listed in table II.

2.3.4 Instrument Mounting and Alignment Requirements - The instrument must be mounted on gimbals, as shown in figure 3. The gimbals should provide a wide range of freedom, for hemispherical coverage.

2.4 Operations

2.4.1 Functional Flow Diagram - The functional flow diagram is shown in figure 4. The diagram shows the sequence of events required for experiment operation.

2.4.2 Instrument Preparation Requirements - After the Shuttle has achieved stable orbit, and before any functions are performed with the instrument, a safety check of the instrument and support equipment is required. Since all the equipment except the control console is outside the pressurized cabin, the safety check is performed visually through a viewing window.

Electrical power is turned on to the equipment from the control console. Probably some warmup time with power on will be required for initial achievement of stable thermal equilibrium; this is estimated to be 3 hours or less.

The launch restraints are released, and the gimbals supporting the instrument are elevated, if this deployment technique is used. The crew then performs a functional check on the experiment system (instrument and support equipment) to verify that the specified operations can be performed.

A calibration sequence follows. Calibrated sources of X-ray photons are uncovered and exposed to the proportional counter detectors. Synthetic stimuli of the electronics will also be required. The calibration sequence can be performed automatically or by manual control. For automatic calibration, a stored computer program is required.

Celestial orientation references must be established in the experiment system. The shuttle orientation data is combined with

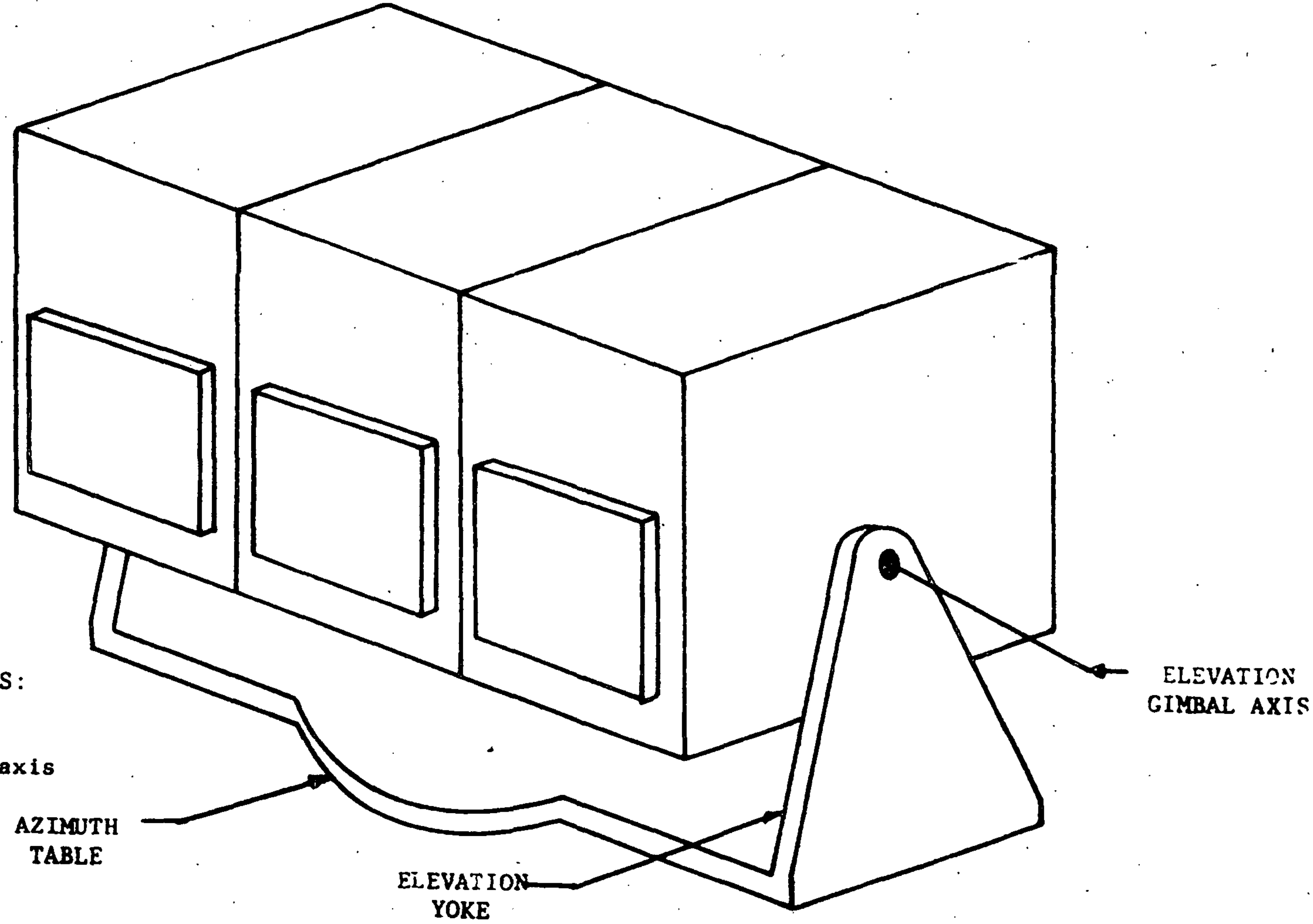
Table I. Scientific Equipment Characteristics

DESCRIPTION	QTY	WIDTH	HEIGHT	LENGTH	DIAMETER	VOLUME	WEIGHT	POWER watts
Collimator	3	0.46 m (18 in.)	0.1 m (4 in.)	0.51 m (20 in.)		*	11.34 kg (25 lb)	
Proportional Counter	3	0.41 m (16 in.)	0.2 m (8 in.)	0.51 m (20 in.)		*	17.24 kg (38 lb)	
Crystal Assembly	3	0.38 m (15 in.)	0.13 m (6 in.)	0.51 m (20 in.)		*	16.78 kg (37 lb)	
Drive Mechanism	3	---	---	---		*	9.07 kg (20 lb)	2 pk
Electronics	1	0.305 m (12 in.)	0.305 m (12 in.)	0.305 m (12 in.)			6.8 kg (15 lb)	10 avg
Structure	1	1.22 m (48 in.)	1.33 m (52.25 in.)	1.84 m (72 in.)			90.72 kg (~200 lb)	

*This equipment contained in a 1.22- by 1.33- by 1.84-m (48- by 52.25- by 72- inch) structural envelope.

Table II. Support Equipment Characteristics

DESCRIPTION	QTY	WIDTH	HEIGHT	LENGTH	DIAMETER	VOLUME	WEIGHT	POWER watts
Gimballed Mount Including Gyros and Star Sensor	1	2.03 m (80 in.) (6)	1.14 m (45 in.) (6)	1.22 m (48 in.) (12) (8)	— (30)		226.8 kg (~500 lb) 9.07 kg (20 lb) 15.87 kg (35 lb)	100 avg, 300 pk 50 100
Wide Coverage X-Ray Detector	1		1.22 m (48 in.)		2.03 m (80 in.)		226.8 kg (~500 lb)	70–170
Controls and Displays Console	1		TBD					



ALIGNMENT REQUIREMENTS:
Gimbal azimuth axis must be parallel to spacecraft principal axis within ± 0.002 rad.

Crystal rotation axis within each module must be parallel to gimbal elevation axis within ± 0.002 rad.

Figure 3. Instrument Mounting

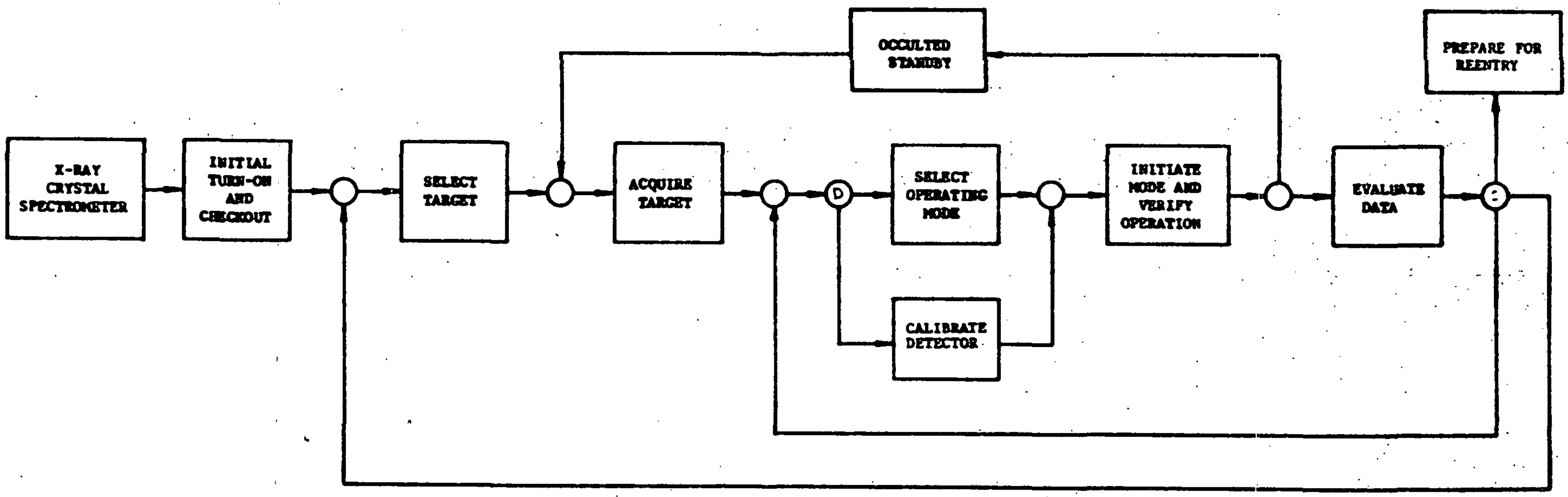


Figure 4. Collimated Plane Crystal Spectrometer: Functional Flow Diagram

the supporting gimbal angle data to define the commands necessary to acquire one of the specified reference stars. The aspect-sensor/star-tracker is oriented to select a specific reference star, and manual acquisition and verification is performed.

Correction of postlaunch misalignments between the detector modules could be performed by the crew, if error sensing and alignment control capabilities are included in the mounting system.

2.4.3 Instrument Operations Requirements - The nature of the data obtained with the collimated plane crystal spectrometer defines the types of operations required with the instrument. Each of the detector modules is an independent spectrometer system, with limited energy range coverage and specific spectral resolution capability. These are determined by the characteristics of the components used: the type of crystal used in the mosaic plates, and the type of proportional counter window and gas. The three modules combine to provide an instrument with wide coverage and good versatility for detailed study of X-ray sources.

The main sequence of operations which must be performed with the instrument during its operation are as follows:

a. Within the viewing constraints defined by the shuttle orientation, occultation by the earth, the gimbal freedom, and occultation by other equipment on the pallet, an X-ray source of high observational priority is selected for detailed study.

b. The nominal coordinates of the source are entered into the pointing control subsystem, to drive the gimbals to their proper orientation.

c. The X-ray orientation system associated with the instrument is then used to refine pointing of the instrument to the source within 0.0003 rad (1 arc minute).

d. The star tracker on stellar aspect sensor is locked onto adequate reference sources, and the pointing control system is set to the tracking mode.

e. The energy scan range for each module is selected and set, as defined in the mission program (based on what data is already available concerning the specific X-ray source).

f. The instrument's scientific data mode is initiated, and operation is monitored during a short interval to verify proper

operation of the crystal scanning drive and of the proportional counters.

g. The instrument operates unattended, acquiring data, as long as the source is within the viewing constraints, or until sufficient sampling has been achieved to reach adequate significance in the data. Periodic monitoring of instrument operation is advisable, and the alert system for transient sources should be operational.

h. Data acquisition is interrupted, as defined in step g above. A display of the data is called up, to verify data quality, instrument condition, and to monitor for unexpected results.

i. A new source is selected for observation, as in step a. Observation program suggestions from the scientists at the ground station, and the outputs from the Wide-Coverage X-Ray Detector, are folded into the mission program to define the source with highest observational priority.

In the interest of acquiring the maximum scientific data possible within the mission duration constraints, the observation program must be carefully planned. The orientation of the experiment should be changed to view another source of interest whenever the source currently under observation approaches the earth's terminator. The ideal situation would be where any source not occulted by the earth could be viewed by the instrument; in this case, the instrument could always be slewed to view another source of interest whenever the earth, or its atmosphere, interferes with the current source. Further details of this requirement are deferred to the discussion on instrument pointing.

Crew involvement in the operation of the instrument is high during the source acquisition phases. The selection of a new source to observe, based on vehicle orientation, viewing constraints, and scientific priority of the sources, could be performed with support from a ground station, or by an onboard computer system. Slewing of the instrument to the selected source and "peaking" of the detected signal is performed manually. Once locked onto the source, the automatic tracking system takes over, and the crew's involvement reduces to occasional monitoring for unusual conditions in the instrument and in the background flux, until the observation is complete or until the source approaches the earth's terminator.

2.4.4 Instrument Postoperation Requirements - The major post-operation functions are basically the reverse of the deployment functions:

a. Place the instrument in the launch orientation.

b. Retract the gimbals (if extension is used).

c. Reset the launch restraints.

e. Turn off electrical power, prepare the instrument for reentry.

These operations are all performed by the crew through the controls and displays console.

2.4.5 Typical Instrument Operation Timelines - The experiment operational characteristics described in the above paragraphs are summarized in table III.

2.5 Environment - The environmental requirements and constraints associated with this instrument are listed in table IV.

The electromagnetic interference susceptibility of the proportional counter detectors is primarily determined by the characteristics of the shielding and isolation that is included in the detector designs. These units have not progressed beyond the conceptual design phase, thus no numerical threshold values can be specified at this time.

Count rate limiters will automatically disable the detectors during crossings of the South Atlantic Anomaly; the detectors will return to normal operation when the particle flux drops below a preset threshold.

2.6 Data - The primary scientific data is described in table V, together with the auxiliary data required. This complete data package represents the basic information which will be used to achieve the specified scientific objectives of the instrument.

In addition to the recording of this data, it must be available for real-time monitoring at the controls and displays console, as defined in 2.8 below.

The possibility of in-flight support by ground-based scientific personnel must be included. Ground support of this type will interface with the crew through the voice link. It is anticipated

Support Requirements / Experiment Operating Sequence		Initial: Safety Check	Initial: Electrical Power-Up	Initial: Release Launch Locks	Initial: Functional Check	Initial: Calibration	Repeated: Select Target	Repeated: Acquire Target	Repeated: Select Operating Mode	Repeated: Initiate Mode & Verify Operation	Repeated: Obtain Data	Repeated: Analyze Data	Repeated: Adjust Observing Program	Repeated: Repeat Operations As Desired	Final: Prepare for ReEntry
	Time (minutes)						3	5	3	1	2 to 120	10	1 to 30		10
Crew Requirements	Astronomer/Astrophysicist	X	X	X	X	X	X	X	X	X		X	X		X
Equipment Requirements	Collimator	X			X		*	X	*	*	X	*	*		
	Crystal	X			X		*	X	*	X	X	*	*		
	Proportional Counter	X	X	*	X	X	*	X	*	X	X	*	*		
	Drive Mechanism	X	X	*	X	*	*	X	*	X	X	*	*		
	Electronics	X	X	*	X	X	*	X	*	X	X	X	*		
	Structure	X			X			X			X				
Support Equipment	Aspect Sensor	X	X		X	*	*	*	*	*	X	*	*		
	Gimballed Mount	X	X	X	X	*	*	X	*	*	X	*	*		
	Wide Coverage X-Ray Detector	X	X	*	X	*	*	*	*	*	*	*	*		
Time - Dependent Functions	Power Profile 10w Continuous + 2w When Crystal Steps														
	Data Profile (KBPS)										2				
	Target														
	Stability														
Remarks		* Asterisk indicates components that require power even if not performing experiment functions.													

*C = Equipment Sharing Code: A = Not Shared; B = Shared Sequentially; C = Shared Simultaneously

Table IV. Environmental Requirements and Constraints

		OPERATING	NONOPERATING
MECHANICAL	Acceleration	<2 m sec^{-2}	With launch restraints set, withstands peak values defined for normal launch and reentry.
	Vibration	TBD	
	Acoustic	TBD	
THERMAL	Absolute temperature limits	281 - 285 K	263 - 293 K
	Differential temperature limits	$\Delta T<2$ K across any module	$\Delta T<2$ K across any module
ATMOSPHERE	Pressure	$< 10^{-4}$ N m^{-2}	$<1.2\times10^{5}$ N m^{-2}
	Humidity	-	<10% (KAP crystals are hygroscopic.)
	Contaminants	Sensitive to water vapor	Clean-room type environment required, 100 000-class
EXTERNAL INTERFERENCES	Magnetic fields	$<2\times10^{-4}$ tesla at portional counters	TBD
	RF fields	$<10^{-TBD}$ v m^{-1}, $<10^{-TBD}$ w m^{-2}	TBD
	Ionizing particles	<0.1 count sec^{-1} in each proportional counter. Counters will automatically power down in high flux conditions such as South Atlantic Anomaly crossings.	Crossings through South Atlantic Anomaly must not generate delayed radioactivity in surrounding equipment and structures.

CLASS	DESCRIPTION	FORMAT	READ-OUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION(2)
SCIENTIFIC							
Spectrometer Counts:	a. Counts of pulses within lower and upper energy limits corresponding to modulo setting (3 modules)	dig. 3x8 bit	30 sec^{-1}	720 bps	Continuously after instrument turned on (1)	360 Mbits	1:1
	b. Count of pulses outside nominal limits (3 modules)	dig. 3x8 bit	3 sec^{-1}	72 bps	(1)	36 Mbits	20:1
	c. Rate (background)	dig. 3x8 bit	6 sec^{-1}	144 bps	(1)	72 Mbits	100:1
Guard Counters	a. Count of all pulses	dig. 3x8 bit	3 sec^{-1}	72 bps	(1)	36 Mbits	20:1
	b. Count of veto pulses	dig. 3x8 bit	3 sec^{-1}	72 bps	(1)	36 Mbits	20:1
Spectrometer Settings (Collimator/Modulo/Proportional Counter Angles)	angular encoders	dig. 3x15 bit	0.3 sec^{-1}	15 bps	(1)	8 Mbits	1:1
Spectrometer Settings	energy step	dig. 3x1 bit	30 sec^{-1}	90 bps	(1)	45 Mbits	20:1
X-Ray Reference Aspect Sensor	Count rates (4 sensors)	dig. 4x4 bit	6 sec^{-1}	96 bps	(1)	48 Mbits	100:1
INSTRUMENT HOUSEKEEPING	100 readout points, commutated sampling	digital 8 bit	1 sec^{-1}	8 bps	(1)	4 Mbits	1:1
CREW'S ANNOTATION	Voice comments Logbook entries	"analog" written	as reqd	BW>1 kHz	(1)	120-144 hours	
SUPPORT EQUIPMENT:							
Wide Coverage X-Ray Detector	Signal pulses + code: detector, time differential	digital 10 bit	50 sec^{-1}	500 bps	(1)	250 Mbits	20:1 (3)
SUBSYSTEMS:							
Spacecraft Attitude Angles	IMU signals	dig. 3x15 bit	0.01sec^{-1}	0.45 bps	(1)		
Gimbal Angles	Angular encoders	dig. 2x15 bit	0.05sec^{-1}	1.5 bps	(1)		
Star tracker/aspect sensor	offset angles	dig. 2x8 bit	0.05sec^{-1}	0.8 bps	(1)	17 Mbits	1:1
	sensed error angles	dig. 2x4 bit	0.1 sec^{-1}	0.8 bps	(1)		
Rate Gyros	angular rates	dig. 2x10 bit	0.5 sec^{-1}	10 bps	(1)		
Timing	clock reference	digital 20 bit	1 sec^{-1}	20 bps	(1)		

NOTES: (1) Equipment is operating and data is recorded at all times between turn-on and shutdown. Recording continues even if not observing a specific source.

(2) Only data buffering is considered, using simple storage, processing and coding techniques. Further compression can be achieved with standard compression algorithms.

(3) Limiting monitor function to large transient X-ray events with preset thresholds yields ratios of 1000:1.

that all commands to the scientific and support equipment will be performed by the crew through the controls and displays console.

Reference timing signals must be available which can be correlated to GMT with absolute errors no greater than 1 msec.

2.7 Pointing - The instrument requires that the axis of the detector field of view be pointed to the source of interest within ±0.0003 rad (±1 arc minute) about the axis of crystal plate rotation, and within ±0.0045 rad (15 arc minutes) about the other two axes. Once the specified orientation accuracy is achieved, it is necessary that it be maintained with a stability of ±0.0003 rad (±1 arc minute) maximum angular drift. A drift rate tolerance of less than 0.00003 rad (0.1 arc minute) in 10 msec is defined. An angular rate tolerance of ±0.0002 rad/sec ($\sim\pm0.01$ degree per sec) has been specified (but not supported by analysis).

To achieve these tolerances, in view of the critical orientation constraints on the Shuttle, it is necessary to mount the detector units on a gimbal system which can provide roughly hemispherical orientation freedom for the field of view axis. Besides providing a method to decouple the instrument from the vehicle, the gimbals must be capable of reorienting the instrument from one source to another with slewing rates of at least 0.05 rad/sec (3 degrees per second) about both gimbal axes. The re-orientation of the instrument is expected to be performed at least twice per orbit.

2.8 Controls and Displays - The functional requirements for the controls and displays required to operate the instrument are listed in tables VI and VII. Table VI lists the requirement for the scientific equipment, and table VII lists the requirements for the support equipment.

2.9 Preflight/Postflight Ground Support - The ground support requirements are detailed. These include equipment and facilities, and a brief discussion of the major functions required after instrument installation.

2.9.1 Ground Support Equipment and Facilities - The major facility and equipment requirements are listed in table VIII.

2.9.2 Test, Checkout, and Calibration - After instrument installation is completed according to established interface requirements, test and checkout of the complete experiment system as an integral package is required. The procedure for these operations is not defined. Some of the operations that will definitely be required can be identified:

Table VI. Scientific Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
FLAT CRYSTAL SPECTROMETER		
Main Power	ON/OFF	ON/OFF
Proportional Counter HV	ON/OFF (3)	ON/OFF (3)
Scan Mode Select	1-6	1-6
Scan Range (Upper)	1-100	1-100
Scan Range (Lower)	1-100	1-100
Scan Rate	1-4	1-4
Scan Sequence	1-3	1-3
Scans Completed		Digital
Scan Step Size	1-6	1-6
Calibration	START/STOP	ON/OFF
Mode Status	START/STOP	READY/OPERATE
Crystal Spectrum (PHA)	ON/OFF	Analog
Crystal Position		Digital
Detector Rate	1-4	Digital
PHA Resolution	1-4	1-4
X-RAY ORIENTATION		
HV Power	ON/OFF	ON/OFF
Calibrate	START/STOP	ON/OFF
Aspect Status	START/STOP	READY/OPERATE

Table VII. Support Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
GIMBAL SYSTEM		
Main Power	ON/OFF	ON/OFF
Primary Instrumentation	ON/OFF	ON/OFF
Shuttle Celestial Orientation	--	DIGITAL (RA+δ AND AZIMUTH)
Gimbal Angles	+/-(2)	DIGITAL
Field of View Orientation	--	DIGITAL (RA+δ)
Source Map	ON/OFF	CRT
Star Sensor Offsets	+/-(2)	DIGITAL
Star Sensor Field	ON/OFF	CRT
Star Sensor Lockon	ON/OFF	INDICATOR
WIDE-COVERAGE X-RAY DETECTOR		
Main Power	ON/OFF	ON/OFF
Primary HV Power Supply	ON/OFF	ON/OFF
Threshold Level Adjust	50 Levels	LEVEL
X-Ray Alert	--	ON/OFF
Experiment Status	START/STOP	READY/OPERATE
Source Coordinates	ON/OFF	(2) DIGITAL
X-Ray Spectrum (PHA)	ON/OFF	ANALOG
Calibration	START/STOP	ON/OFF
Rate Attenuator Select	1-6	1-6
Module HV Power	OFF (154 max)	
Module Integrity		GO/NO-GO

Table VIII. Ground Support Requirements

EQUIPMENT	Controlled Environment Storage Container Handling/Installation Fixture Module Alignment Fixture Calibrated X-Ray Sources Checkout/Calibration Monitor System
FACILITIES	Clean Room (100 000-class low humidity Prelaunch Environment Control Facility

a. Signal test of each module with true X-ray photon flux into the crystal plates, monitored at the data recording point.

b. Alignment verification between the three detector modules.

c. Operational verification of the gimbal/detector module system for slewing rates, accuracies of pointing.

d. Star sensor images at the controls and displays console.

A final calibration of the detector characteristics is required prior to launch and must be repeated after the instrumentation returns from orbit and before it is dismantled.

2.9.3 Accessibility Requirements - After prelaunch checkout and calibration, access will be required to the scientific equipment if it has been subjected to environments outside those specified in table IV for checkout. Also, refill of the thin-window proportional counter is required as shortly before launch as is practical.

2.10 Post-Mission Refurbishment - After completion of a mission in which successful observations were performed, the only refurbishment servicing required will be flushing and replenishment of the gas mixture in the proportional counters.

2.11 Orbital Parameters - The scientific equipment is compatible with all orbits which have been suggested for the shuttle. The only criteria to be considered in a trade study of orbital parameters are:

a. Minimum ionized particle background flux.

b. Minimum attenuation by atmosphere.

c. Maximum viewing capability of specific sources.

In some respects, the latter two considerations go together, and improve with orbit altitude. In contrast, the particle flux increases with altitude and is a complex function of orbital inclination.

3. PROGRAMMATICS

The information in this section consists mostly of subjective estimates, which are generally not supported (and probably cannot be supported) by analysis. Personal experiences with simpler instrumentation have been used for extrapolation to the instrument.

3.1 Equipment Cost and Schedule - NASA has two estimates for the cost of this instrument. One, from the HEAO-B spacecraft development contract is for $6 million (1971) with 3 years development time, for installation in an unmanned spacecraft. The other is from the Shuttle Payload Planning Activity, which indicates $20 million (1969) and 4 years development time. The latter estimates are for a single, simpler module than the three considered herein. NASA estimates are used for extrapolation to the estimates shown in table IX.

3.2 Safety Considerations - As currently designed, all the scientific equipment and the majority of the support equipment (except for the controls and displays console and the data management subsystem's tape recorder) are located outside the crew compartment. There are no pyrotechnic or explosive devices required for this instrumentation. Extravehicular activity is not considered for this program. Therefore there are no hazards specifically associated with this instrumentation.

3.3 Reliability - Equipment reliability depends primarily on the level of effort devoted to this issue during design, development, fabrication, and test phases.

Probable mean-time-between-failure estimates are given in table X, for the three types of cost estimates used in table IX.

4. NOTES

4.1 Bibliography - This report contains information obtained from the following documents. The documents are not referred to in the text.

a. Reference Earth Orbital Research and Applications Investigations (Blue Book), Volume II, Astronomy. January 15, 1971.

b. High Resolution Bragg Crystal Spectrometer Experiment Information, The Aerospace Corporation, prepared by A. B. C. Walker, Jr., Space Physics Laboratory, July 30, 1970.

c. Technical Proposal to National Aeronautics and Space Administration for the High Energy Astronomy Observatory (HEAO), prepared by A. B. C. Walker, Jr., The Aerospace Corporation, and J. R. P. Angel, Columbia University, September 1970.

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)			(1.00)	(1.60)	(1.80)	(0.70)		$ 5.10
PRODUCTION-FIRST ARTICLE				(1.70)	(2.80)	(2.80)		7.30
								$ 12.40

TABLE IX - SCHEDULE AND COST ESTIMATES, COLLIMATED PLANE CRYSTAL SPECTROMETER

Table X. Mean Time Between Failure Estimates

UNIT \ LEVEL	LABORATORY UNITS	SPACE HARDENED	SPACE QUALIFIED
Detector Modules	200	5 000	10 000
Mounting Frame	2 000	10 000	25 000
Central Data Processor	500	4 000	10 000
NOTE: MTBF values are in hours.			

4.2 Abbreviations

ASMDS	Astronomy Sortie Missions Definition Study
avg	average
bps	bits per second
BW	bandwidth
cm	centimeter
CRT	cathode ray tube
dig.	digital
fJ	femtojoule
FWHM	full-width, half-maximum
GMT	Greenwich Mean Time
HEAO	High Energy Astronomy Observatory
HV	high voltage
IMU	Inertial Measurement Unit
K	degrees Kelvin
KAP	potassium ammonium phosphate
kHz	kilo Hertz
keV	kiloelectron volt
kg	kilogram
m	meter
msec	millisecond
Mbits	megabits
MTBF	mean-time-between-failure
N	newton
NASA	National Aeronautics and Space Administration
PC	proportional counter
PHA	pulse height analyzer
pk	peak
rad	radian
RA	Right Ascension
RF	radio frequency
sec	second
S.P.P.A.	Shuttle Payload Planning Activity
sr	steradian
TBD	To Be Determined
w	watt
δ	declination angle
ΔT	temperature difference

.2.11 NARROW-BAND SPECTROMETER / POLARIMETER

ASM-EXP-204-5
February 25, 1972

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

Baseline Experiment Definition Document (BEDD): ASMDS Narrow-Band Spectrometer/Polarimeter

Contract GC1-115076

Prepared by:

J. Dawson

Approved by:

H. O. Ankenbruck
Project Manager

The Bendix Corporation
Navigation & Control Division
Denver Facility
Denver, Colorado

CONTENTS

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CONTENTS (Concluded)

1. INTRODUCTION

The purpose of this document is to define a baseline Narrow-Band Spectrometer/Polarimeter instrument for the Astronomy Sortie Missions Definition Study (ASMDS).

The scientific objectives, configurations, operational requirements, environmental requirements, data, pointing, and controls and displays requirements, estimated ground support equipment, and postmission refurbishment requirements are identified.

2. DISCUSSION

2.1 Scientific Objectives - The Narrow-Band Spectrometer/Polarimeter is designed to measure the intensity and polarization of the emissions from X-ray sources, at two energies corresponding to continuum radiation, and at seven others corresponding to emission lines of ionized elements. The intensity measurements are critical to the determination of the temperature of the source, which is determined by comparing the intensity ratio at the two continuum energies, and by the ratios of line intensities of two ionization levels of the same element. Relative abundances of species are determined by line intensity ratios for different elements. The polarization measurements are critical to the determination of the mechanisms of X-ray flux generation from the sources.

2.2 Instrument Description - The instrument contains nine detector modules. Each module, of approximately conical shape, detects X-ray photons corresponding to a narrow energy band. Typical module dimensions are shown in figure 1.

Energy band selection is accomplished by Bragg reflection of the incident radiation from a mosaic of crystal pieces arranged on the inside surface of a conical shell. The reflected photons are detected by a sectored proportional counter system, close to the apex of the cone. In each module, the crystal pieces used to make up the mosaic are cut at a specific angle to the crystal faces, and oriented on the conical shell so as to achieve Bragg reflection at the specified energy, together with a focusing effect as shown in figure 2. This focusing reduces the detector size required, and hence also improves the signal-to-noise ratio by reducing the background signals.

For photons that satisfy the Bragg condition, the efficiency of Bragg reflection is dependent on the angle between the plane of polarization and the plane that contains the incident beam direction and the normal to the Bragg plane. When the two planes are

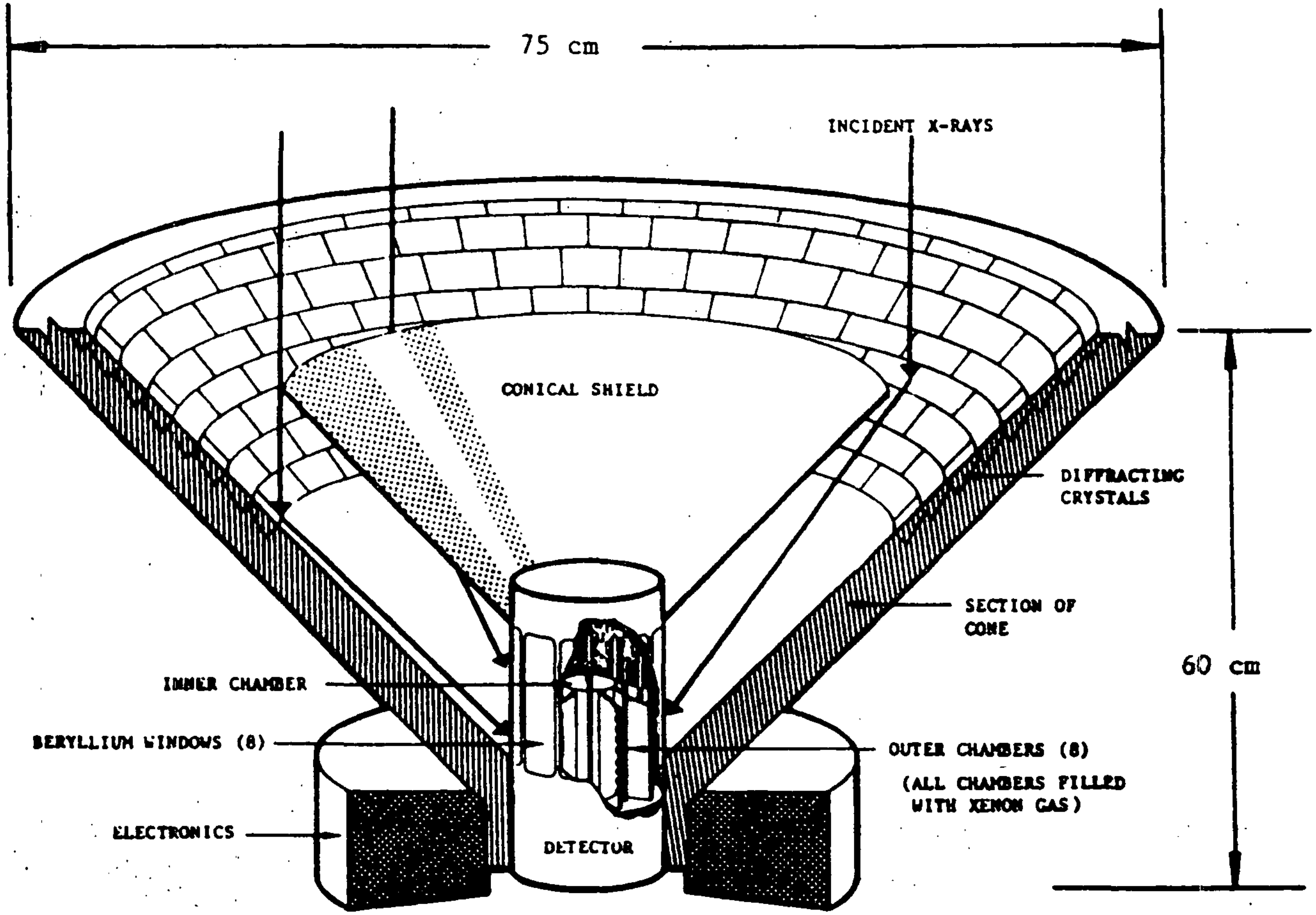


Figure 1. Individual Detector Module, Narrow-Band Spectrometer/Polarimeter

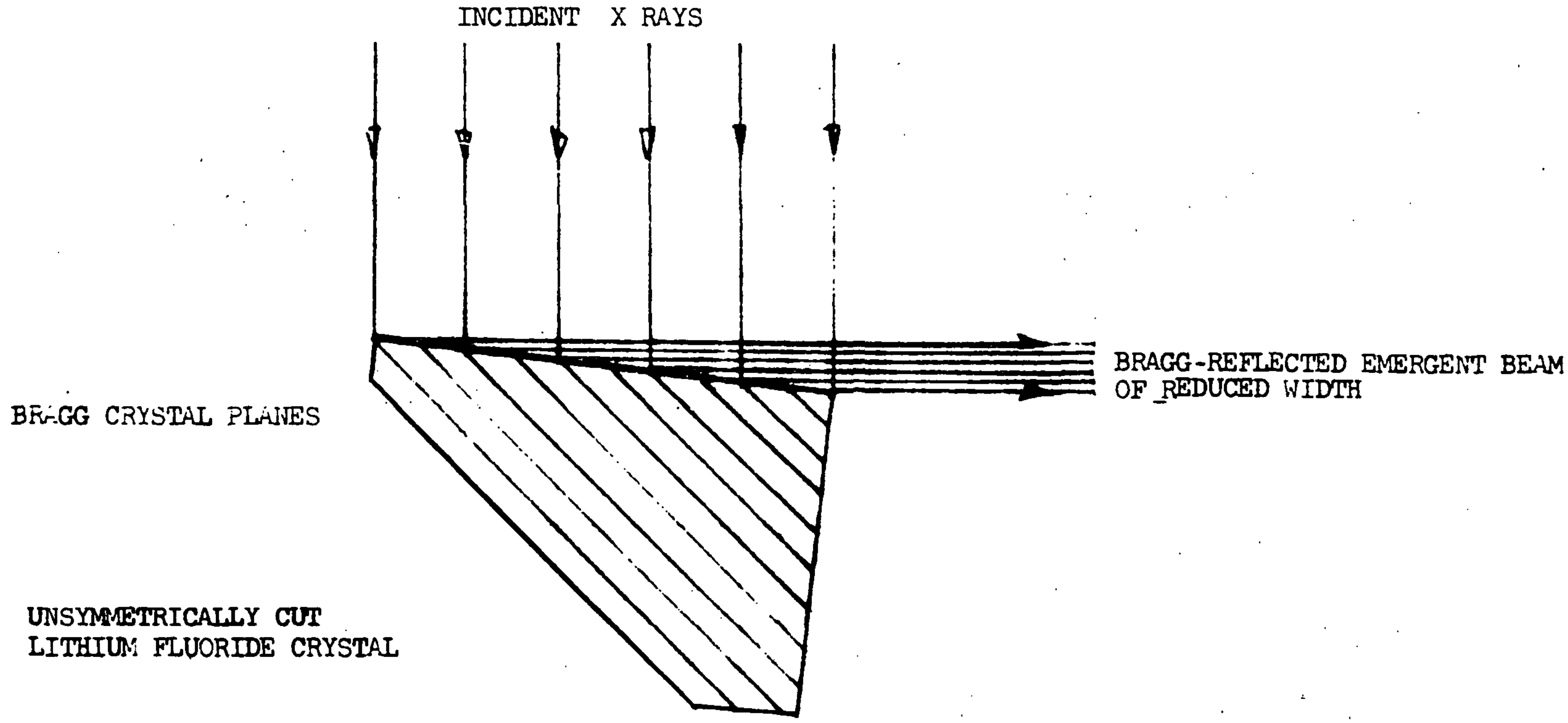


Figure 2. Focussing Effect of Unsymmetrical Bragg Crystals

orthogonal, the reflection efficiency is maximum; when the planes coincide, the reflection efficiency is nil. In each module, the detector system consists of a proportional counter with eight distinct sectors, each covering an arc of $\pi/4$ rad (45°) on the conical crystal mosaic. A comparison of the intensities detected in the individual sectors (or in sector pairs) yields the required measure of the extent of X-ray polarization, and the approximate direction of the plane of polarization.

The nine modules are mounted on a structural frame that holds them so that all view the same source. The frame is mounted on a gimbal system, to allow viewing of specific X-ray sources without requiring re-orientation of the Shuttle, and to decouple drifts in the Shuttle's orientation from the instrument axis.

Each module includes an electronics package for amplification, preprocessing (gating) and identification coding of the detector signals, and for power conversion.

In addition to the nine modules, the instrument includes a Central Data Processor that contains memory units, pulse height analyzers, and readout and control circuitry.

The Bragg reflection mechanism used for X-ray reflection and focusing limits the field of view of the detector units to narrow angles, with $\Delta\theta$=0.009 radian full-width half-maximum as typical for most of the modules. Therefore the detector instrumentation must be adjusted to within $\pm$0.0015 rad by the observation crew, "peaking" the detected count rate, to insure that accurate flux and polarization measurements can be performed.

If this instrument is considered from the viewpoint of general X-ray signal detection, the narrow spectral sensitivity ($\Delta E/E$= 0.003 or 0.02 for each module) and narrow field of view ($\Delta\theta \simeq 30$ minutes of arc) translate into an instrument with very low throughput. It is designed for a highly specialized application of measurement of X-ray intensity and polarization from selected sources, and has limited capability as a general X-ray signal detector.

2.3 Physical Configuration and Power Requirements - Descriptions of experiment and support equipment characteristics and mounting arrangements follow. These requirements are tentative, subject to extensive modifications if integration trade studies show that the scientific objectives can be achieved with simpler equipment and requirements.

2.3.1 Interface Block Diagram - The equipment interface diagram is shown in figure 3. This diagram identifies the major interfaces between the instrument and the spacecraft subsystems.

2.3.2 Scientific Equipment Characteristics - Preliminary scientific equipment characteristics are listed in table I.

2.3.3 Support Equipment Characteristics - Preliminary estimates of the characteristics of the support equipment required for this instrument are listed in table II.

2.3.4 Instrument Mounting and Alignment Requirements - The proposed mounting arrangement for the nine detector modules and some of the support equipment is shown in the sketch in figure 4.

2.4 Operations - The participation of the crew in the functions associated with this instrument is detailed.

2.4.1 Functional Flow Diagram - A gross outline of the functions required is shown in figure 5.

2.4.2 Instrument Preparation Requirements - After the Shuttle has achieved stable orbit, and before any functions are performed with the instrument, a safety check of the instrument and support equipment is required. Since all the equipment except the control console is outside the pressurized cabin, the safety check is performed visually through a viewing window.

Electrical power is turned onto the equipment from the control console. Probably some warmup time with power on will be required for initial achievement of stable thermal equilibrium; this is estimated to be 3 hours or less.

The launch restraints are released, and the gimbals supporting the instrument are elevated, if this deployment technique is used. The crew then performs a functional check on the experiment system (instrument and support equipment) to verify that the specified operations can be performed.

A calibration sequence follows. Due to the narrow band nature of the spectrometer/polarimeter modules, it is not considered possible to supply each detector module with a controlled photon beam stimulus from an X-ray source. The calibration must therefore be limited to artificial stimuli of the electronic systems. The calibration sequence can be performed automatically or by manual control. For automatic calibration, a stored computer program is required.

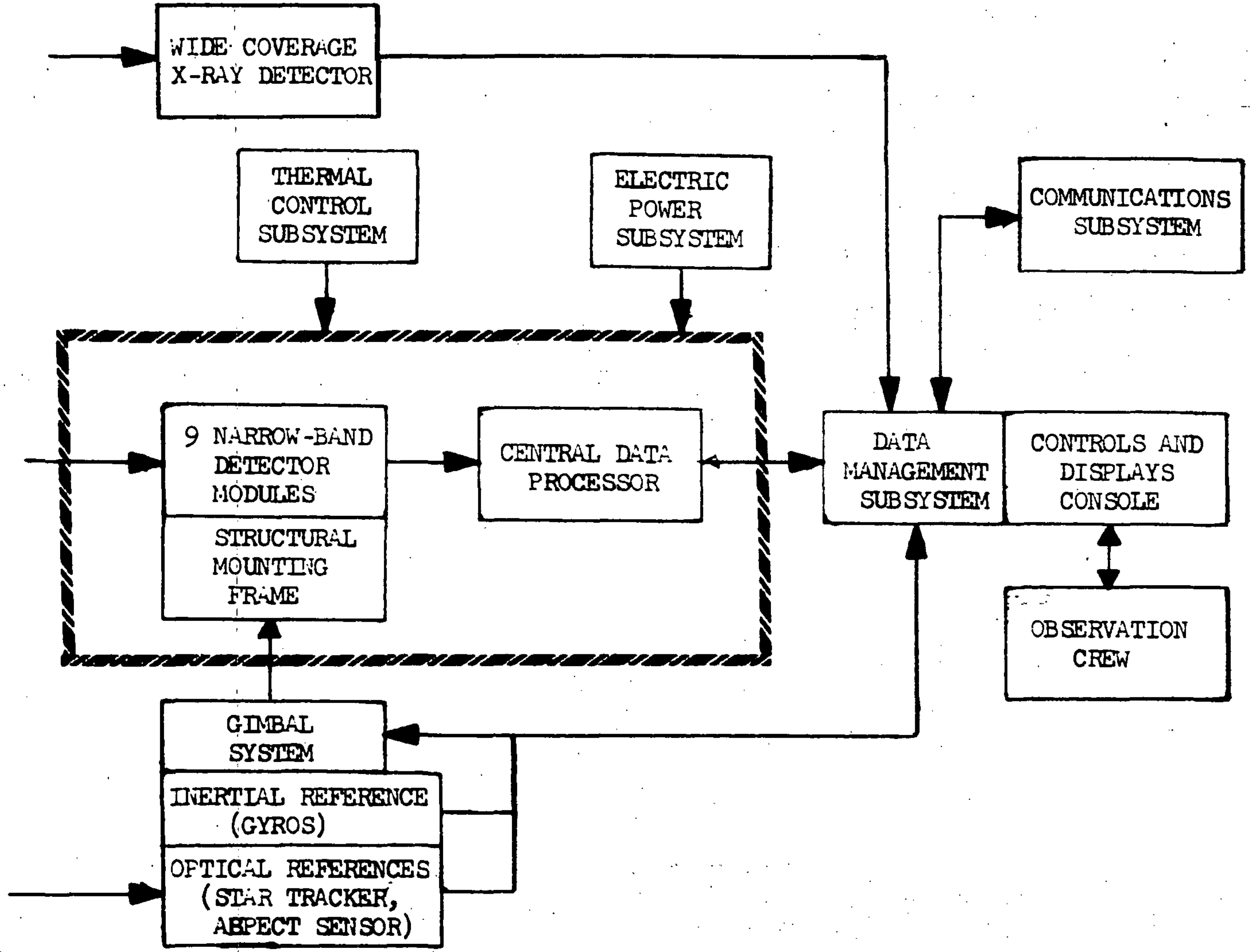


Figure 3. Interface Block Diagram

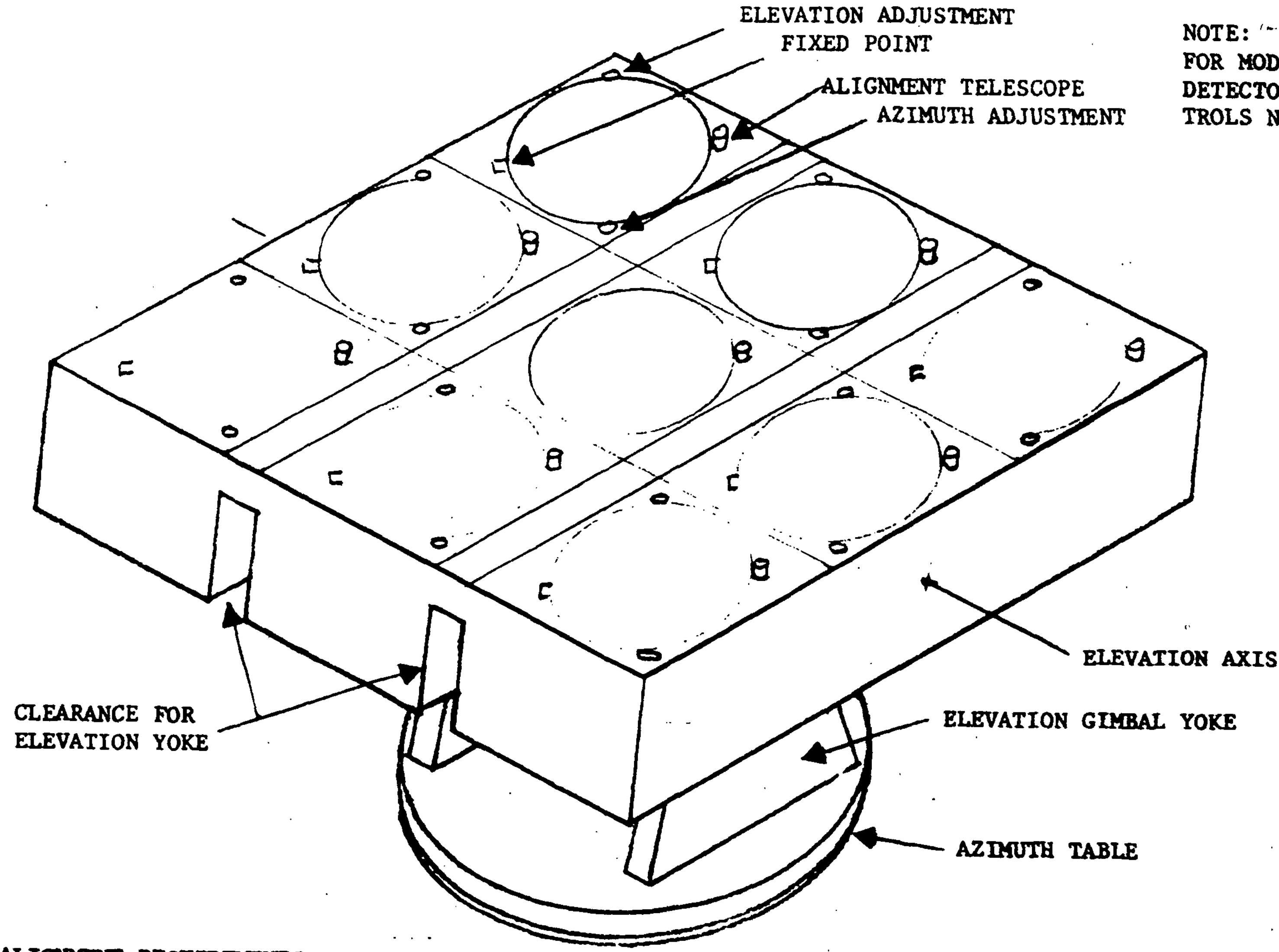
Table I. Scientific Equipment Requirements

DESCRIPTION	QTY	WIDTH cm	HEIGHT cm	LENGTH cm	DIAMETER cm	VOLUME m^3	WEIGHT kg	POWER watts
CRYSTAL MOSAIC/DETECTOR MODULE 6.00 ± 0.06 keV (Continuum I)	1	-	60	-	75	0.27	27	5.5
CRYSTAL MOSAIC/DETECTOR MODULE 6.64 ± 0.01 keV (Fe^{+24})	1	-	60	-	75	0.27	27	5.5
CRYSTAL MOSAIC/DETECTOR MODULE 6.64 ± 0.06 keV (Fe^{+24})	1	-	60	-	75	0.27	27	5.5
CRYSTAL MOSAIC/DETECTOR MODULE 6.89 ± 0.01 keV (Fe^{+25})	1	-	60	-	75	0.27	27	5.5
CRYSTAL MOSAIC/DETECTOR MODULE 6.89 ± 0.06 keV (Fe^{+25})	1	-	60	-	75	0.27	27	5.5
CRYSTAL MOSAIC/DETECTOR MODULE 7.43 ± 0.06 keV (Co^{+26})	1	-	60	-	75	0.27	27	5.5
CRYSTAL MOSAIC/DETECTOR MODULE 7.99 ± 0.01 keV (Ni^{+27})	1	-	60	-	75	0.27	27	5.5
CRYSTAL MOSAIC/DETECTOR MODULE 8.17 ± 0.01 keV (Fe^{+25})	1	-	60	-	75	0.27	27	5.5
CRYSTAL MOSAIC/DETECTOR MODULE 8.31 ± 0.06 keV (continuum II)	1	-	60	-	75	0.27	27	5.5
CENTRAL DATA PROCESSOR	1	35	50	100	-	0.18	50	20
STRUCTURAL FRAME	1	250	60	250	-	3.8	250	-

Table II. Support Equipment Characteristics

DESCRIPTION	QTY	WIDTH cm	HEIGHT cm	LENGTH cm	DIAMETER cm	VOLUME m^3	WIEGHT kg	POWER watts
WIDE COVERAGE X-RAY DETECTOR	1		120	200	4.0	250		70-170
GIMBAL SYSTEM INCLUDING GYROS, STAR TRACKER/ASPECT SENSOR	1				TBD			
CONTROLS AND DISPLAY CONSOLE	1				TBD			
THERMAL CONTROL	-	-	-	-	-	-	-	50-200

NOTE: REQUIREMENT FOR MODULE ALIGNMENT DETECTORS AND CONTROLS NOT DEFINED



**PRELAUNCH ALIGNMENT REQUIREMENTS:
AZIMUTH GIMBAL AXIS MUST BE ALIGNED TO SPACECRAFT YAW REFERENCE AXIS WITHIN ± 0.0003 RAD (± 1 ARC MINUTE)**

GIMBAL AXES MUST CROSS AT INSTRUMENT'S CENTER OF GRAVITY

Figure 4. Instrument Mounting Arrangement

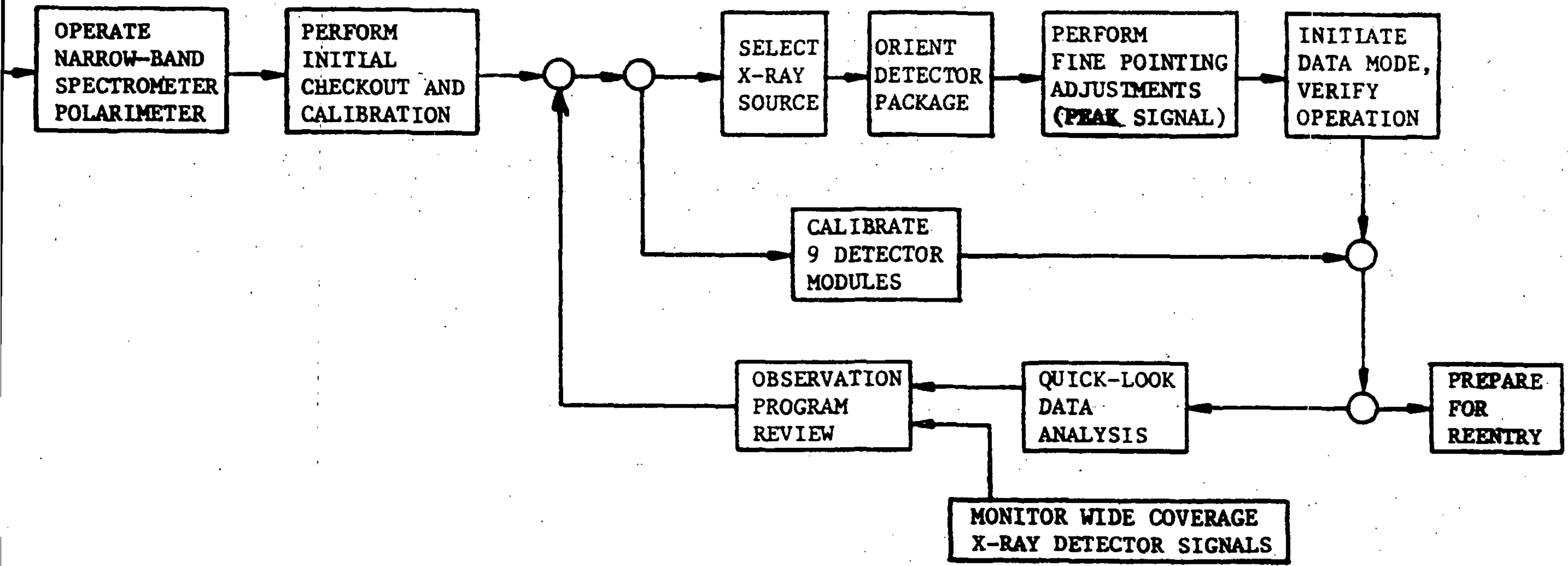


Figure 5. Functional Flow Diagram

Celestial orientation references must be established in the experiment system. The Shuttle orientation data are combined with the supporting gimbal angle data to define the commands necessary to acquire one of the specified reference stars. The aspect-sensor/star-tracker is oriented to select a specific reference star, and manual acquisition and verification is performed.

Correction of postlaunch misalignments between the detector modules could be performed by the crew, if error sensing and alignment control capabilities are included in the mounting system. If not available, the instrument must be scanned (in two directions in a sort of raster scan) over a point source of X rays, to determine the relative misalignments between modules for postflight compensation of the data.

2.4.3 Instrument Operation Requirements - The instrument has only one mode of operation during scientific data acquisition, namely, all detector modules viewing a specific X-ray source simultaneously.

Observation periods of 45 minutes or less are adequate for observation of 15 of the known X-ray sources. The source structure or flux from all other known X-ray sources is such that statistically significant data acquisition will require observation periods greater than 45 minutes. These observation times can be achieved by observing each weak source over more than one orbital period.

In the interest of acquiring the maximum scientific data possible within the mission duration constraints, the observation program must be carefully planned. The orientation of the experiment should be changed to view another source of interest whenever the source currently under observation approaches the earth's terminator. The ideal situation would be where any source not occulted by the earth could be viewed by the instrument; in this case, the instrument could always be slewed to view another source of interest whenever the earth or its atmosphere interferes with the current source. Further details of this requirement are deferred to the discussion on instrument pointing.

Crew involvement in the operation of the instrument is high during the source acquisition phases. The selection of a new source to observe, based on vehicle orientation, viewing constraints, and scientific priority of the sources, could be performed with support from a ground station, or by an on-board computer system. Slewing of the instrument to the selected source and "peaking" of the detected signal is performed manually. Once locked onto the source, the automatic tracking system takes over,

and the crew's involvement reduces to occasional monitoring for unusual conditions in the instrument and in the background flux, until the observation is complete or until the source approaches the earth's terminator.

2.4.4 Instrument Post-Operation Requirements - The major post-operation functions are basically the reverse of the deployment functions:

a. Place the instrument in the launch orientation.

b. Retract the gimbals (if extension is used).

c. Reset the launch restraints.

d. Turn off electrical power, prepare the instrument for reentry. These operations are all performed by the crew through the Controls and Displays Console.

2.4.5 Typical Instrument Operation Timelines - The experiment opera-operational characteristics described in the above paragraphs are summarized in table III.

2.5 Environment - The environmental requirements and constraints associated with this instrument are listed in table IV. The electromagnetic interference susceptibility of the proportional counter detectors is primarily determined by the characteristics of the shielding and isolation that is included in the detector designs. These units have not progressed beyond the conceptual design phase, thus no numerical threshold values can be specified.

Count rate limiters will automatically disable the detectors during crossings of the South Atlantic Anomaly; the detectors will return to normal operation when the particle flux drops below a preset threshold.

2.6 Data - The primary scientific data is described in table V, together with the auxiliary data required. This complete data package represents the basic information which will be used to achieve the specified scientific objectives of the instrument.

In addition to the recording of this data, it must be available for real-time monitoring at the Controls and Displays Console, as defined in 2.8.

Table III. Typical Operational Timeline

Support Requirements \ Operation Sequence		INITIAL: SAFETY CHECK	INITIAL: ELECTRICAL POWER ON	INITIAL: RELEASE LAUNCH RESTRAINTS	INITIAL: FUNCTIONAL CHECK	INITIAL: CALIBRATION	INITIAL: STAR SENSOR ORIENTATION	INITIAL: GYRO REFERENCES	INITIAL: (DETECTOR MODULE ALIGNMENT CHECK)	REPEATED: SELECT TARGET	REPEATED: ACQUIRE TARGET	REPEATED: INITIATE DATA ACQUISITION AND VERIFY OPERATION	REPEATED: DATA ACQUISITION	REPEATED: DATA QUICK-LOOK ANALYSIS	REPEATED: ADJUST OBSERVING PROGRAM	REPEATED: SELECT TARGET (REPEAT AS REQD)	FINAL: SET GIMBALS TO LAUNCH POSITION	FINAL: SET LAUNCH RESTRAINTS	FINAL: TURN POWER OFF
	TIME (MINUTES)	2	1 (180)	2	10	30	5	2	(180)	1	1	1	30-300	5	5	1	5	1	1
OBSERVATION CREW		X	X	X	X	X	X	X	(X)	X	X	X		X	X	X	X	X	X
SCIENTIFIC EQUIPMENT	DETECTOR UNITS AND FRAME	X	X	X	X	X	*	*	(X)	*	X	X	X	*	*	*	X	X	-
SCIENTIFIC EQUIPMENT	CENTRAL DATA PROCESSOR	X	X	*	X	X	*	*	*	*	X	X	X	X	*	*	*	*	-
SUPPORT EQUIPMENT	WIDE-COVERAGE X-RAY DETECTOR	X	X	*	*	*	*	*	(X)	*	*	*	X	*	*	*	*	*	-
SUPPORT EQUIPMENT	GIMBAL SYSTEM	X	X	X	X	X	X	X	(X)	X	X	X	X	*	*	X	X	X	-
SUPPORT EQUIPMENT	STAR SENSOR	X	X	*	X	*	X	X	(X)	X	X	X	X	*	*	X	*	*	-
SUPPORT EQUIPMENT	GYROS	X	X	*	X	*	*	X	(X)	X	X	X	X	*	*	X	*	*	-
SUPPORT EQUIPMENT	CONTROLS AND DISPLAYS CONSOLE	X	X	X	X	X	X	X	X	X	X	X	*	X	*	X	X	X	X

NOTES: * EQUIPMENT NOT SPECIFICALLY REQUIRED FOR THIS FUNCTION, BUT REMAINS TURNED ON AND DRAWING POWER
( ) VALUES ENCLOSED IN PARENTHESES HAVE NOT BEEN DEFINED AS REQUIRED

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Table IV. Environmental Requirements/Constraints

		OPERATING	NONOPERATING
MECHANICAL	Acceleration	$<2\ m\ sec^{-2}$	With launch restraints set, withstands peak values defined for normal launch and reentry.
	Vibration	TBD	
	Acoustic	TBD	
THERMAL	Absolute temperature limits	281 - 285 K	253 - 293 K
	Differential temperature limits	$\Delta T<2$ K across any module	$\Delta T<2$ K across any module
ATMOSPHERE	Pressure	$<10^{-10}\ N\ m^{-2}$	$<1.2x10^{5}\ N\ m^{-2}$
	Humidity	-	<10% (Lithium fluoride crystals are hygroscopic!)
	Contaminants	Sensitive to water vapor	Clean-room type environment required, 100 000-class
EXTERNAL INTERFERENCES	Magnetic fields	$<2x10^{-4}$ tesla at proportional counters	TBD
	RF fields	$<10^{-TBD}vm^{-1}$, $<10^{-TBD}wm^{-2}$	TBD
	Ionizing particles	<0.01 count sec^{-1} in each proportional counter. Counters will automatically power down in high flux conditions such as South Atlantic Anomaly crossings	Crossings through South Atlantic Anomaly must not generate delayed radioactivity in surrounding equipment and structures.

Table V. Recorded Data Requirements

CLASS	DESCRIPTION	FORMAT	READOUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION (2)
SCIENTIFIC	Signal pulses with code: sector, module, differential time	digital 10 bit	100 sec^{-1}	1 000 bps	Continuously after instr turned on (1)	500 Mbits	20:1
	Count rate meters, commutated 9 modules	digital 10 bit	10 sec^{-1}	100 bps	(1)	50 Mbits	100:1
INSTRUMENT HOUSEKEEPING	100 readout points, commutated sampling	digital 8 bit	1 sec^{-1}	8 bps	(1)	4 Mbits	1:1
CREW'S ANNOTATION	Voice comments Logbook entries	"analog" written	as reqd	BW>1kHz	(1)	120-144 hours	-
SUPPORT EQUIPMENT:							
Wide Coverage X-Ray Detector	Signal pulses + code: detector, time difference	digital 10 bit	50 sec^{-1}	500 bps	(1)	250 Mbits	20:1 (3)
SUBSYSTEMS:							
Spacecraft Attitude Angles	IMU signals	digital 3x15 bit	0.01 sec^{-1}	0.45 bps	(1)	17 Mbits	1:1
Gimbal Angles	Angular encoders	digital 2x15 bit	0.05 sec^{-1}	1.5 bps	(1)		
Star Tracker/Aspect Sensor	Offset angles Sensed error angles	digital 2x8 bit digital 2x4 bit	0.05 sec^{-1} 0.1 sec^{-1}	0.8 bps 0.8 bps	(1) (1)		
Rate Gyros	Angular rates	digital 2x10 bit	0.5 sec^{-1}	10 bps	(1)		
Timing	Clock reference	digital 20 bit	1 sec^{-1}	20 bps	(1)		

NOTES:
(1) Equipment is operating and data is recorded at all times between turn-on and shutdown. Recording continues even if not observing a specific source.
(2) Only data buffering is considered, using simple storage, processing and coding techniques. Further compression can be achieved with standard compression algorithms.
(3) Limiting monitor function to large transient X-ray events with preset thresholds yields ratios of 1 000:1.

The possibility of in-flight support by ground-based scientific personnel must be included. Ground support of this type will interface with the crew through the voice link. It is anticipated that all commands to the scientific and support equipment will be performed by the crew through the Controls and Displays Console.

Reference timing signals must be available which can be correlated to GMT with absolute errors no greater than 1 msec.

2.7 Pointing - The instrument requires that the axis of the detector field of view be pointed to the source of interest within ± 0.0015 rad (± 5 arc minutes) about two axes orthogonal to the field of view axis. Once the specified orientation accuracy is achieved, it is necessary that it be maintained with a stability of ± 0.0003 rad (± 1 arc minute) maximum angular drift. There are no angular rate tolerances.

To achieve these tolerances, in view of the critical orientation constraints on the Shuttle, it is necessary to mount the detector units on a gimbal system which can provide roughly hemispherical orientation freedom for the field of view axis. Besides providing a method to decouple the instrument from the vehicle, the gimbals must be capable of reorienting the instrument from one source to another with slewing rates of at least 0.05 rad sec^{-1} (3 degrees per second) about both gimbal axes. This re-orientation of the instrument is expected to be performed at least twice per orbit.

2.8 Controls and Displays - The functional requirements for the controls and displays required to operate the instrument are listed in tables VI and VII. Table VI lists the requirements for the scientific equipment, and table VII lists the requirements for the support equipment.

2.9 Preflight/Postflight Ground Support - The ground support requirements are detailed. These include equipment and facilities, and a brief discussion of the major functions required after instrument installation.

2.9.1 Ground Support Equipment and Facilities - The major facility and equipment requirements are listed in table VIII.

2.9.2 Test, Checkout, and Calibration - After instrument installation is completed according to established interface requirements, test and checkout of the complete experiment system as an integral package is required. The procedure for these operations is not defined. Some of the operations that will definitely be required can be identified:

Table VI. Scientific Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
MAIN POWER	ON/OFF	ON/OFF
HV POWER	ON/OFF (9)	ON/OFF (9)
EXPERIMENT STATUS	START/STOP	READY/OPERATE
CALIBRATION	START/STOP	CALIBRATION ON/OFF
X-RAY COUNT RATE	ON/OFF	DIGITAL
X-RAY SPECTRUM (PHA)	ON/OFF	ANALOG
X-RAY DETECTOR SELECT	1-9	1-9
MISALIGNMENT DETECTOR	ON/OFF (8)	2-AXIS NULL DETECTOR (8)
AZIMUTH ADJUSTMENT	+/-(8)	---
ELEVATION ADJUSTMENT	+/-(8)	---

Table VII. Support Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
GIMBAL SYSTEM:		
MAIN POWER	ON/OFF	ON/OFF
PRIMARY INSTRUMENTATION	ON/OFF	ON/OFF
SHUTTLE CELESTIAL ORIENTATION	---	DIGITAL (RA+δ)
GIMBAL ANGLES	+/-(2)	DIGITAL
FIELD OF VIEW ORIENTATION	---	DIGITAL (RA+δ)
SOURCE MAP	ON/OFF	CRT(?)
STAR SENSOR OFFSETS	+/-(2)	DIGITAL
STAR SENSOR FIELD	ON/OFF	CRT(?)
STAR SENSOR LOCK ON	ON/OFF	INDICATOR
WIDE-COVERAGE X-RAY DETECTOR:		
MAIN POWER	ON/OFF	ON/OFF
PRIMARY HV POWER SUPPLY	ON/OFF	ON/OFF
THRESHOLD LEVEL ADJUST	50 LEVELS	LEVEL
X-RAY ALERT	---	ON/OFF
EXPERIMENT STATUS	START/STOP	READY/OPERATE
SOURCE COORDINATES	ON/OFF	(2) DIGITAL
X-RAY SPECTRUM (PHA)	ON/OFF	ANALOG
CALIBRATION	START/STOP	CALIBRATION ON/OFF
RATE ATTENUATOR SELECT	1-6	1-6
MODULE HV POWER	OFF (154 MAX)	---
MODULE INTEGRITY	---	GO/NO-GO

Table VIII. Ground Support Requirements

EQUIPMENT	Controlled Environment Storage Container
	Handling/Installation Fixture
	Module Alignment Fixture
	Calibrated X-Ray Sources
	Checkout/Calibration Monitor System
FACILITIES	Clean Room (100 000-class low humidity)
	Prelaunch Environment Control Facility

a. Signal test of each module with true X-ray photon flux into the detectors, monitored at the data recording point.

b. Verification of alignment among the nine detector modules.

c. Operational verification of the gimbal/detector module system for slewing rates, accuracies of pointing.

d. Star sensor images at Controls and Displays Console.

A final calibration of the detector characteristics is required prior to launch, and repeated after the instrumentation returns from orbit and before it is dismantled.

2.9.3 Accessibility Requirements - After prelaunch checkout and calibration, access is not required to the scientific equipment if it has not been subjected to environments outside those specified in table IV.

2.10 Post-Mission Refurbishment - After completion of a mission in which successful observations were performed, the only refurbishment servicing required will be flushing and replenishment of the gas mixture in the sectored proprotional counters that are used in each module.

A successful mission should be expected to evoke an interest in substituting some of the narrow-band detector modules to investigate a different energy band, such as the Si^{+12} line at 1.87 keV and the Si^{+13} line at 2.00 keV.

2.11 Orbital Parameters - The scientific equipment is compatible with all orbits which have been suggested for the Shuttle. The only criteria to be considered in a trade study of orbital parameters are:

a. Minimum ionized particle background flux.

b. Minimum attenuation by atmosphere.

c. Maximum viewing capability of specific sources.

In some respects, the latter two considerations go together, and improve with orbit altitude. In contrast, the particle flux increases with altitude.

3. PROGRAMMATICS

The information in this section consists mostly of subjective estimates which are generally not supported, and probably cannot be supported, by any extensive analysis. Personal experiences with simpler instrumentation have been used for extrapolation into vastly different equipment characteristics.

3.1 Equipment Cost and Schedule - It is indeed fortunate that NASA has already made one estimate of the cost of this instrument, for the Shuttle Payload Planning Activity (MSFC 1969-70). From the information supplied in the final documentation for task II of that activity, estimates of $18 million (1969) and 5 years development are extracted. It is assumed that this equipment cost and schedule is for equipment slightly better than laboratory brass-board type. A series of possible estimates are shown in table IX.

3.2 Safety Considerations - As currently designed, all the scientific equipment and the majority of the support equipment (except for the Controls and Displays Console and the tape recorder from the Data Management Subsystem) are located outside the crew compartment. There are no pyrotechnic or explosive devices required. Extravehicular activity is baselined out of the Astronomy Sortie Program.

The only identified hazard associated with the equipment would arise just prior to reentry, if the launch restraints were not to engage. The instrument could rip off from its cantilevered moorings on the gimbal, and penetrate the crew compartment, during a period of high deceleration. This catastrophe has about the same probability of occurrence as that of a collision of the Shuttle with a 100-kg meteor during the 7-day mission.

3.3 Reliability - Equipment reliability depends primarily on the level of effort devoted to this subject during the design, development, fabrication, and test phases of the equipment.

Probable mean-time-between-failure estimates are given in table X, for the three types of cost estimates associated with table IX.

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)			(1.90)	(2.70)	(1.70)			$ 6.30
PRODUCTION-FIRST ARTICLE			(1.00)	(3.60)	(3.80)	(1.80)		10.20
								$ 16.50

TABLE IX - SCHEDULE AND COST ESTIMATES, NARROW-BAND SPECTROMETER/POLARIMETER

Table X. Mean Time Between Failure Estimates

UNIT \ LEVEL	LABORATORY UNITS	SPACE HARDENED	SPACE QUALIFIED
Detector Modules	200	5 000	10 000
Mounting Frame	2 000	10 000	25 000
Central Data Processor	500	4 000	10 000

NOTE: MTBF values are in hours.

4. NOTES

4.1 Bibliography - This report contains information obtained from the following documents. The documents are not referred to in the text.

a. Reference Earth Orbital Research and Applications Investigations (Blue Book), Volume II, Astronomy. January 15, 1971.

b. A Proposal to Fly a Multichannel X-Ray Spectrometer/ Polarimeter Aboard the HEAO. The Boeing Company, Boeing Research Laboratories Report No. D180-10116-1 (1969) (Authored by Dr. R. Graham Bingham et al).

4.2 Abbreviations

ASMDS	Astronomy Sortie Missions Definition Study
avg	average
bps	bits per second
cm	centimeters
CRT	cathode ray tube
FWHM	full-width, half-maximum
GMT	Greenwich Mean Time
HV	High Voltage
IMU	Inertial Measurement Unit
instr	instrument
K	degrees Kelvin
keV	kiloelectron volt
kg	kilogram
M	mega
m	meter
msec	millisecond
MTBF	mean-time-between-failure
N	Newton
PHA	Pulse Height Analyzer
pk	peak
RA	Right Ascension
rad	radian
RF	radio frequency
sec	second
S.P.P.A.	Shuttle Payload Planning Activity
sr	steradian
TBD	To Be Determined
v	volt
w	watt
δ	declination angle

2.12 GAMMA-RAY SPECTROMETER

ASM-EXP-204-7
March 10, 1972

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

Baseline Experiment Definition Document (BEDD):
ASMDS Gamma-Ray Spectrometer

Contract GC1-115076

Prepared by:

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Figure

CONTENTS (Concluded)

1. INTRODUCTION

The purpose of this document is to define a baseline Gamma-Ray Spectrometer instrument for the ASMDS.

The scientific objectives, configurations, operational requirements, environmental requirements, data, pointing, and controls and displays requirements, estimated ground support equipment and post-mission refurbishment requirements are identified.

2. DISCUSSION

2.1 Scientific Objectives - Measurements have been performed on a large number of celestial sources in the X-ray range. This instrument is designed to extend the range of measurements into higher energies. Specific scientific objectives are:

a. To perform an exploratory search for sources of X-ray and γ-ray line emissions in the 0.06 to 10 MeV energy interval.

b. To determine the location, intensity, and detailed spectrum of X-ray and γ-ray sources.

c. To search for new X-ray and γ-ray sources.

d. To observe time variations in the intensity and spectral details of discrete X-ray and γ-ray sources.

e. To study the origin, isotropy, and spectral details of the diffuse X-ray and γ-ray background.

2.2 Instrument Description - This instrument uses four lithium-drifted germanium (Ge(Li)) crystals as primary detectors for gamma-ray photons in the energy range of 0.06 to 10 MeV. These detectors can provide photon energy resolution as high as 0.1 percent at 1 MeV, as compared to 8% to 15% for scintillation crystal detectors, or 20% to 40% for gas-filled proportional counters.

The field of view of the four coaxial, cryogenically-cooled Ge(Li) crystal detectors is limited, by active anticoincidence techniques, to a conical region with 0.5 radian (approximately 30°) full-width half-maximum. The active anticoincidence shield is constructed from four blocks of sodium-doped cesium iodide (CsI(Na)), to provide collimation and rejection of all events not entering

through the defined aperture. The configuration of the detector unit is shown in figure 1.

The scintillation shield is sectored into independent pieces, which provide the capability of measuring events in the higher energy range (above 2 MeV) by detecting the decay photons from pair production (e^+e^-). Events detected simultaneously in two of the four Ge(Li) crystals also can often be identified as the results of pair production, thus increasing the total sensitivity of the instrument.

To obtain the excellent energy resolution capabilities of Ge(Li) crystal detectors it is necessary to operate them at cryogenic temperatures. Within a wide temperature range (20 to 200 K) the detected line profile width is proportional to the absolute temperature. Better energy resolution corresponds to lower temperature. To be useful as a detector of spectral line emissions from celestial sources, it is necessary that the detectors be operated at temperatures below 90 K.

To preserve the drifted lithium ions within the germanium matrix, it is mandatory that the crystal temperature be maintained below 200 K (-100° F) <u>at all times after manufacture</u>. The detectors must be attached to cryostats during all handling operations.

The ionizing particle flux environment that prevails in the South Atlantic Anomaly can produce severe detrimental effects on this instrument. Interactions both in the spacecraft structures and in the instrument itself by the trapped proton flux (and also by the energetic cosmic nuclei) lead to the production of γ-emitting isotopes which contribute to the background level, and reduce the sensitivity for detection of valid events from the sources of interest.

The angular resolution of this instrument is poor. This is a fundamental characteristic of γ-ray detectors, for which the background count rate is larger than the signal count rate unless the field of view is sufficiently wide. For this instrument, background and signal count rates are approximately equal. The detection sensitivity is maximum in the direction of the instrument's main axis, decreases to half the maximum value at 0.25 rad (15 degrees) from the axis, and drops to zero at 0.6 rad (35 degrees) from the axis. All photons entering the detectors within this field of view are accepted. It is not possible to identify the actual direction of photon incidence <u>within</u> this field of view.

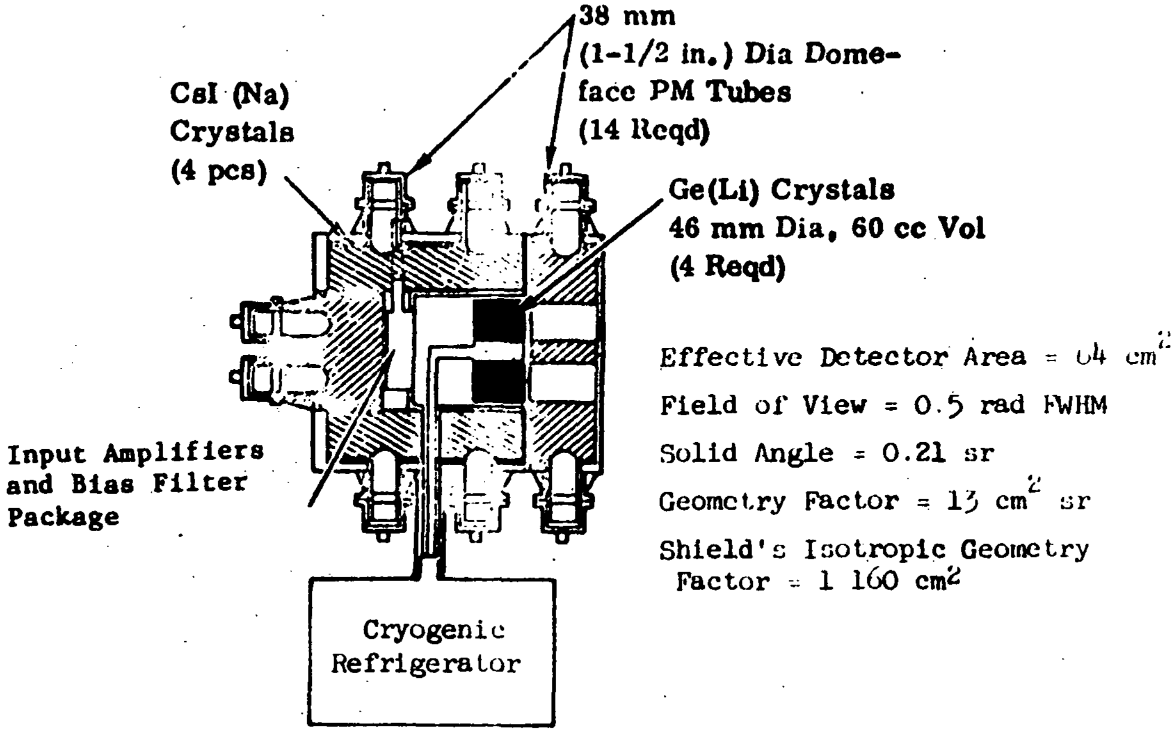

Figure 1. Gamma-Ray Spectrometer Detector Package

2.3 Instrument Interfaces and Characteristics - Experiment and support equipment characteristics and mounting arrangements are described below. These requirements are tentative, subject to extensive modifications if integration trade studies show that the scientific objectives can be achieved with simpler equipment and requirements.

2.3.1 Equipment Interface Diagram - The equipment interface diagram is shown in figure 2. This diagram identifies the major interfaces between the instrument and the spacecraft subsystems.

2.3.2 Scientific Equipment Characteristics - Preliminary scientific equipment characteristics are listed in table I.

2.3.3 Support Equipment Characteristics - Preliminary estimates of the characteristics of the support equipment required for this instrument are listed in table II.

2.3.4 Instrument Mounting and Alignment Requirements - The proposed mounting arrangement for the detector unit, the cryogenic refrigerator, and some of the support equipment is shown in the sketch in figure 3. The electronics package need not be mounted on the orientable gimbal system, but it must be close to the detector package. A suitable location is within the structure of the deployment mechanism.

Instrument mounting alignment tolerances are not severe. Actual alignment of the instrument (through the gimbals and pallet systems) must be lined up with the spacecraft reference axes within ± 0.0175 rad (± 1.0 degree). The true reference direction offsets between the instrument and the spacecraft axes must be known to 0.00175 rad (0.1 degree) before launch.

2.4 Operations - The participation of the crew in the functions associated with this instrument is detailed.

2.4.1 Functional Flow Diagram - A gross outline of the functions requiredis shown in the Functional Flow Diagram, figure 4.

2.4.2 Instrument Preparation Requirements - After the Shuttle has achieved stable orbit, and before any functions are performed with the instrument, a safety check of the instrument and support equipment is required. Since all the equipment except the control console is outside the pressurized cabin, the safety check is performed visually through a viewing window.

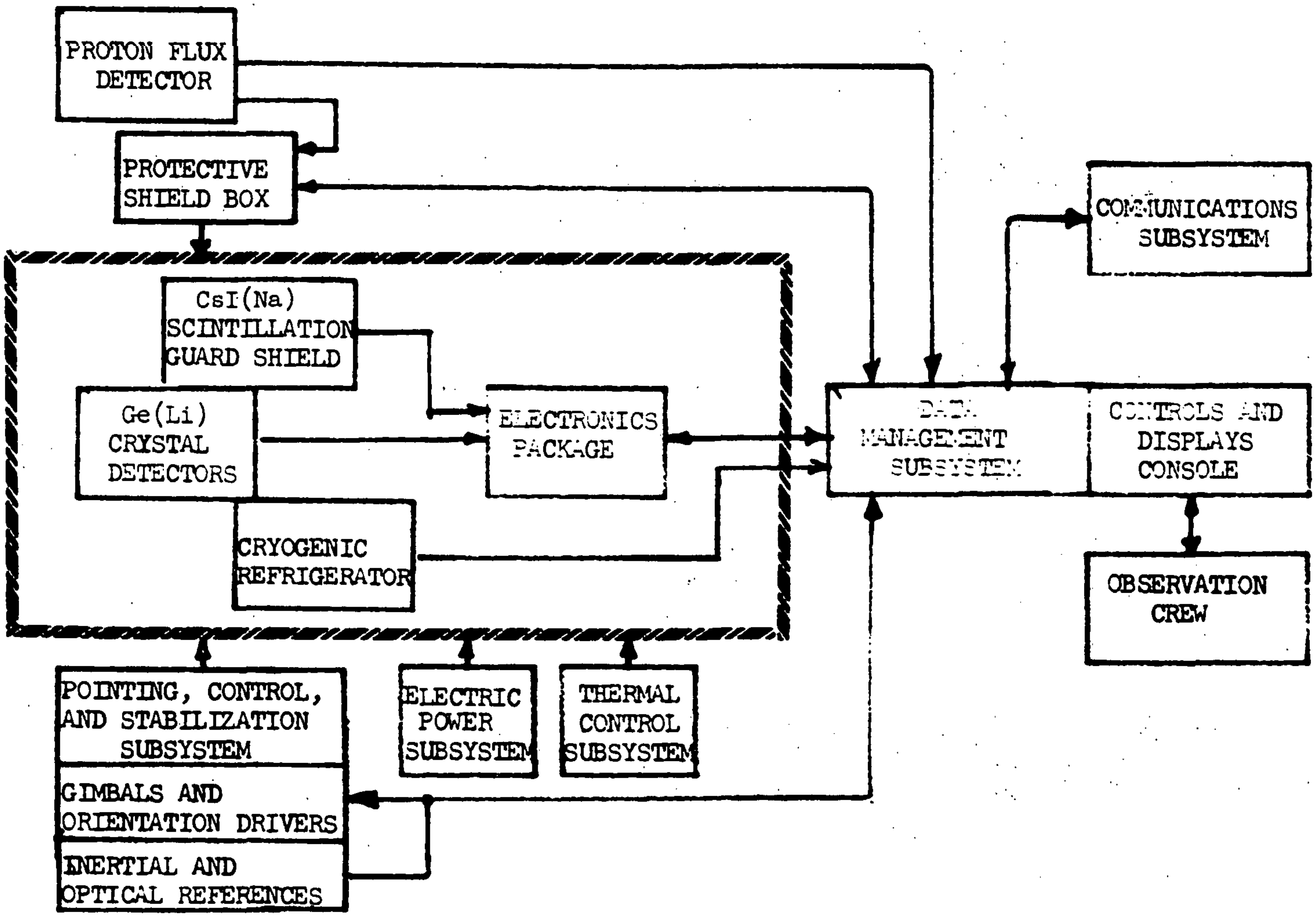

Figure 2. Interface Block Diagram

Table I. Scientific Equipment Characteristics

DESCRIPTION	DIMENSIONS							
	QTY	WIDTH	HEIGHT	LENGTH	DIAMETER	VOLUME	WEIGHT	POWER
		cm	cm	cm	cm	m^3	kg	watts
Detector Unit	1			33	30	0.024	120	10
Cryogenic Refrigerator	1	30	30	30		0.027	10	
Mounting Frame	1	33	30	60			15	
Electronics Package	1	30	30	30		0.027	10	20

Table II. Support Equipment Characteristics

DESCRIPTION	DIMENSIONS							
	QTY	WIDTH cm	HEIGHT cm	LENGTH cm	DIAMETER cm	VOLUME m3	WEIGHT kg	POWER watts
Protective Shield Box	1	90	120	90		1	400	50 pk 0 avg
Proton Flux Detector	1	40	32 & 8 STD-OFFS	40	0.064	0.064	13.5	6 PK 4AVG
Gimbals and Deployment Mechanism	1	TBD						TBD
Controls and Displays Console	1	TBD						TBD

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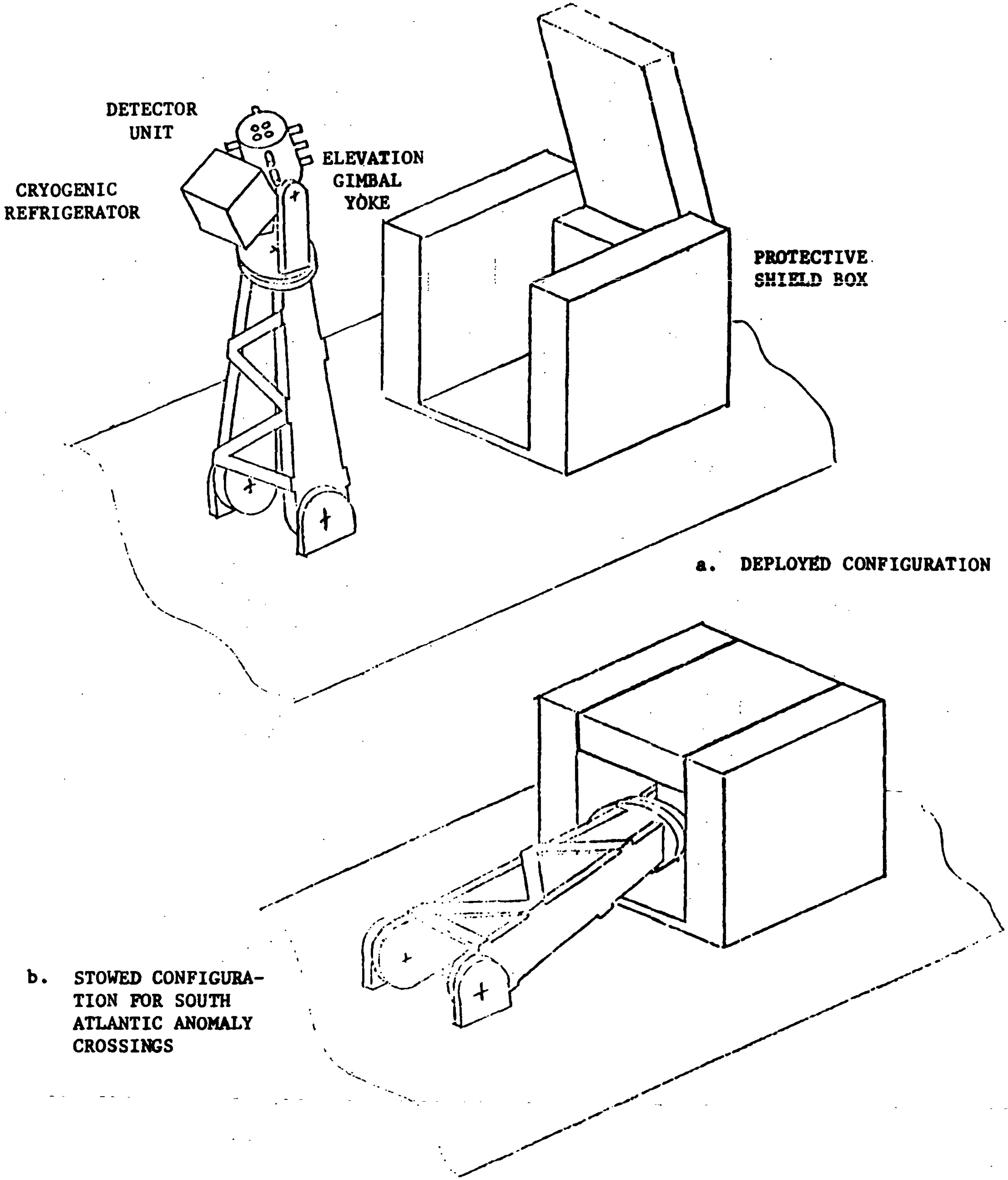

Figure 3. Suggested Mounting Arrangement

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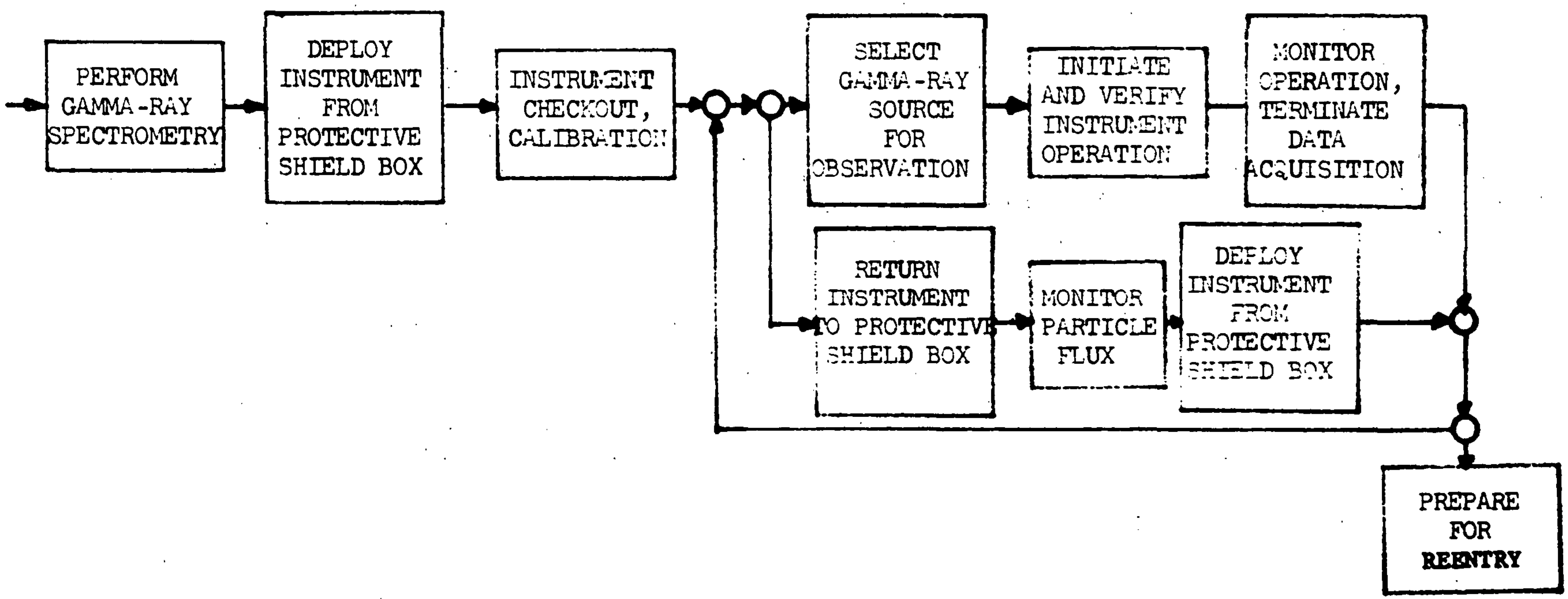

Figure 4. Functional Flow Diagram, Gamma-Ray Spectrometer

34k

In addition to the standard checkout requirements that are common to all space astronomy instruments, the gamma-ray spectrometer must be deployed before operation. The deployment sequence is:

a. The cover of the protective shield box is raised.

b. The (hinged) deployment boom mechanism is erected and locked.

c. The moisture barrier over the Ge(Li) crystals is removed.

The temperature of the Ge(Li) crystal detectors is a critical parameter, for detector operation and performance, and for detector "health" and stability. This parameter will require careful monitoring by the crew, to insure that it is within the required range.

The detectors must be pre-cooled before launch, to minimize the time required after orbit to achieve equilibrium at the desired cryogenic temperatures. To prevent the buildup of ice on the cooled detectors, they must be covered with a moisture barrier which is removed after orbit is achieved. (The problem of ice or frost buildup will also have to be solved for HEAO-B, so that a similar solution to HEAO's may be used.)

The presence of two intense spectral lines in the background photon flux reduces the need for detector calibration. The e^+e^- annihilation radiation at 0.511 MeV in the atmosphere's albedo, and the 2.225 MeV line from the (n, γ) process of deuterium formation provide continuous calibration references for the Ge(Li) and CsI(Na) detectors.

2.4.3 Instrument Operation Requirements - The γ-ray spectrometer has only one primary data acquisition mode, in which the field of view of the instrument is oriented toward a specific region of the celestial sphere which contains a source of interest. It is possible that a slow scanning motion of the detector orientation, about one axis (specifically the elevation axis of figure 3) would be used to provide some angular measurement accuracy superior to the full field-of-view width. This procedure is tentatively baselined for this instrument, although it has not been specified as a requirement in the original experiment descriptions.

Observation period durations for γ-ray sources, due to the low signal-to-background characteristics, must necessarily be very long.

High statistical significance will not be achieved with observation periods on the order of one hour. Each source of interest must be observed over several orbits, due to the low total effective detector area (64 cm^2) and low input photon flux (10^{-4} cm^{-2} sec^{-1} keV^{-1} or less).

The observational approach therefore will require that each selected source or region be studied for as long as possible, within the constraints of earth occultation, earth albedo interference, and vehicle-related obscuration.

In the interest of acquiring the maximum scientific data possible within the mission duration constraints, the observation program must be carefully planned. The orientation of the instrument should be changed to view another source of interest whenever the source currently under observation becomes subject to interference from the earth's albedo. The ideal situation would be where the instrument could be slewed to view another source of interest free from external interference whenever the earth or its atmosphere interfere with the currently-observed source.

Crew involvement in the operation of the instrument is high during the source acquisition phases. The selection of a new source to observe, basedon vehicle orientation, viewing constraints, and scientific priority of the known sources, could be performed with support from a ground station or by an on-board computer system. Slewing of the instrument to the selected source is performed manually. Once locked onto the source, the automatic tracking system takes over, and the crew's involvement reduces sharply, mostly to monitoring for unusal conditions in the background flux. This continues until the source becomes subject to external interference.

Special procedures are required for crossings through the South Atlantic Anomaly. The support equipment (table II) includes a monitoring instrument which alerts the crew to the detection of an ionizing particle flux above a preset threshold, as would be observed when entering the outskirts of the South Atlantic Anomaly. The crew must then

a. Power down the photon detectors.

b. Return the detector package to the "caged" position of its gimbals.

c. Lower the instrument package into the protective shield box (see figure 4) and lower the box cover.

2.4.4 Instrument Post-Operation Requirements - The major post-operation functions are:

a. Turn off the detector package power.

b. Place the instrument in the "caged" gimbal orientation.

c. Retract the instrument package into the protective shield box, lower the box cover.

d. Reset the launch restraints.

e. Turn off all other electrical power, and prepare the instrument for reentry.

These operations are all performed by the crew through the controls and displays console.

2.4.5 Typical Instrument Operation Timelines - The experiment operational characteristics described in the above paragraphs are summarized in table III.

2.5 Environment - The environmental requirements and constraints associated with this instrument are listed in table IV.

Many of the quantitative values shown in table IV are strongly influenced by the actual design configuration of the instrument equipment. The conceptual design phase for a similar instrument (for HEAO-B) is currently nearing completion; the instrument described herein may be expected to have similar requirements. However, actual firm requirements are as yet undefined.

It is emphasized that the requirement to maintain the temperature of the lithium-drifted germanium crystal detectors below 200 K (-100° F) is not negotiable. Should the temperature rise above this value, the detector characteristics would be severely deteriorated.

The approach suggested in this document for protection of the detectors from deterioration due to the energetic proton flux in the South Atlantic Anomaly should be subject to extensive analyses and reevaluations.

2.6 Data - The primary scientific data is described in table V, together with the auxiliary data required. This complete data package represents the basic information which will be used to

Table III. Typical Operational Timelines

INITIAL

Operation sequence / Support requirements	SAFETY CHECK	ELECTRICAL POWER ON	RELEASE LAUNCH RESTRAINTS AND DEPLOY DETECTOR PACKAGE	FUNCTIONAL CHECK	ELECTRONICS CALIBRATION	ESTABLISH ORIENTATION REFERENCES
TIME (MINUTES)	2-20	2	2	10	10	5
CREW PARTICIPATION (ASTRONAUT/ASTRONAUT)	X	X	X	X	X	X
SCIENTIFIC EQUIPMENT: DETECTOR UNIT	-	X	*	X	*	*
SCIENTIFIC EQUIPMENT: ELECTRONICS UNIT	-	X	*	X	X	*
SCIENTIFIC EQUIPMENT: CRYOGENIC REFRIGERATOR	X	X	*	*	*	*
SUPPORT EQUIPMENT: GIMBALS/DEPLOYMENT SYSTEM	X	X	X	X	*	X
SUPPORT EQUIPMENT: PROTECTIVE SHIELD BOX	X	-	X	X	-	-
SUPPORT EQUIPMENT: PHOTON FLUX DETECTOR	X	*	*	X	X	*
SUPPORT EQUIPMENT: CONTROLS AND DISPLAYS CONSOLE	X	X	X	X	X	X
POWER REQUIREMENTS: SCIENTIFIC EQUIPMENT	30W CONTINUOUSLY					
POWER REQUIREMENTS: SUPPORT EQUIPMENT	300	300	350	350	300	300
GIMBAL REQUIREMENTS: SLEWING			X	X		
GIMBAL REQUIREMENTS: SOURCE TRACKING						

REPEATED (DATA ACQUISITION CYCLE)

Operation sequence / Support requirements	SELECT SOURCE OF INTEREST	ORIENT DETECTOR UNIT	INITIATE DATA ACQUISITION AND VERIFY OPERATION	SCIENTIFIC DATA ACQUISITION	QUICK-LOOK DATA ANALYSIS	SELECT SOURCE OF INTEREST (START OF NEW OBSERVATION CYCLE)
TIME (MINUTES)	1	1	1	45-450	5	1
CREW PARTICIPATION (ASTRONAUT/ASTRONAUT)	X	X	X		X	X
SCIENTIFIC EQUIPMENT: DETECTOR UNIT	*	X	X	X	*	*
SCIENTIFIC EQUIPMENT: ELECTRONICS UNIT	*	X	X	X	X	*
SCIENTIFIC EQUIPMENT: CRYOGENIC REFRIGERATOR	*	X	X	X	*	*
SUPPORT EQUIPMENT: GIMBALS/DEPLOYMENT SYSTEM	*	X	X	X	*	*
SUPPORT EQUIPMENT: PROTECTIVE SHIELD BOX	-	-	-	-	-	-
SUPPORT EQUIPMENT: PHOTON FLUX DETECTOR	*	*	*	*	*	*
SUPPORT EQUIPMENT: CONTROLS AND DISPLAYS CONSOLE	X	X	X	X	X	X
POWER REQUIREMENTS: SUPPORT EQUIPMENT	350	350	300	300	300	300
GIMBAL REQUIREMENTS: SLEWING	X					X
GIMBAL REQUIREMENTS: SOURCE TRACKING		X	X	X	X	

REPEATED (SOUTH ATLANTIC ANOMALY CYCLE)

Operation sequence / Support requirements	DETECT INCREASING BACKGROUND OF IONIZING PARTICLES	POWER DOWN DETECTOR HIGH VOLTAGES	CAGE DETECTOR PACKAGE GIMBALS	RETRACT DETECTOR PACKAGE INTO PROTECTIVE SHIELD BOX	WAIT UNTIL BACKGROUND FLUX DROPS BELOW THRESHOLD	OBSERVE END OF HIGH BACKGROUND FLUX	DEPLOY DETECTOR PACKAGE FROM PROTECTIVE SHIELD BOX	RELEASE DETECTOR PACKAGE GIMBALS	TURN ON DETECTOR HIGH VOLTAGES	SELECT SOURCE OF INTEREST (START OF NEW OBSERVATION CYCLE)
TIME (MINUTES)	0.1	0.1	0.5	2	5-20	1	2	0.5	0.5	1
CREW PARTICIPATION (ASTRONAUT/ASTRONAUT)	X	X	X	X		X	X	X	X	X
SCIENTIFIC EQUIPMENT: DETECTOR UNIT	X	*	*	*	*	*	*	*	X	*
SCIENTIFIC EQUIPMENT: ELECTRONICS UNIT	X	X	*	*	*	*	*	*	X	*
SCIENTIFIC EQUIPMENT: CRYOGENIC REFRIGERATOR	X	*	*	*	*	*	*	*	*	*
SUPPORT EQUIPMENT: GIMBALS/DEPLOYMENT SYSTEM	X	*	X	X	*	*	X	X	*	*
SUPPORT EQUIPMENT: PROTECTIVE SHIELD BOX	-	-	-	X	X	X	X	-	-	-
SUPPORT EQUIPMENT: PHOTON FLUX DETECTOR	X	X	X	X	X	X	X	*	*	*
SUPPORT EQUIPMENT: CONTROLS AND DISPLAYS CONSOLE	X	X	X	X	X	X	X	X	X	X
POWER REQUIREMENTS: SUPPORT EQUIPMENT	300	300	350	350	300	300	350	350	300	350
GIMBAL REQUIREMENTS: SLEWING			X	X			X	X		X
GIMBAL REQUIREMENTS: SOURCE TRACKING	X									

FINAL

Operation sequence / Support requirements	LOWER DAM DETECTOR HIGH VOLTAGES	CAGE DETECTOR PACKAGE GIMBALS	RETRACT DETECTOR PACKAGE INTO PROTECTIVE SHIELD BOX	RELOCK LAUNCH RESTRAINTS	TURN OFF ELECTRICAL POWER NOT USED FOR CRYOGENIC REFRIGERATOR	(RECHARGE FOR REENTRY)
TIME (MINUTES)	0.1	0.5	2	2	1	
CREW PARTICIPATION (ASTRONAUT/ASTRONAUT)	X	X	X	X	X	X
SCIENTIFIC EQUIPMENT: DETECTOR UNIT	*	*	*	*	-	-
SCIENTIFIC EQUIPMENT: ELECTRONICS UNIT	*	*	*	*	-	-
SCIENTIFIC EQUIPMENT: CRYOGENIC REFRIGERATOR	*	*	*	*	*	*
SUPPORT EQUIPMENT: GIMBALS/DEPLOYMENT SYSTEM	*	X	X	X	-	-
SUPPORT EQUIPMENT: PROTECTIVE SHIELD BOX	-	-	-	-	-	-
SUPPORT EQUIPMENT: PHOTON FLUX DETECTOR	*	*	*	*	-	-
SUPPORT EQUIPMENT: CONTROLS AND DISPLAYS CONSOLE	X	X	X	X	X	X
POWER REQUIREMENTS: SUPPORT EQUIPMENT	300	350	350	350	150	150
GIMBAL REQUIREMENTS: SLEWING		X	X			
GIMBAL REQUIREMENTS: SOURCE TRACKING						

NOTE: * ASTERISK INDICATES EQUIPMENT NOT SPECIFICALLY REQUIRED FOR THIS FUNCTION, BUT REMAINS TURNED ON AND DRAWING POWER.

Table IV. Environmental Requirements/Constraints

		OPERATING	NONOPERATING
MECHANICAL	Acceleration	<2 m sec^{-2}	With launch restraints set, withstands peak values defined for normal launch and reentry.
	Vibration	TBD	
	Acoustic	TBD	
THERMAL	Absolute temperature limits	Instrument: 281 to 285 K Ge(Li) detectors must be precooled before launch to <90 K, and operated between 30 and 90 K.	Instrument: 253 to 293 K Ge(Li) detectors must be maintained below 200 K (-100° F) at all times.
	Differential temperature limits	$\Delta T<2$ K across any module	$\Delta T<2$ K across any module
ATMOSPHERE	Pressure	$<10^{-4}$ N m^{-2}	$<1.2\times10^{5}$ N m^{-2}
	Humidity	-	Cryogenically cooled detectors must be protected from frost buildup.
	Contaminants	Cryogenically cooled detectors should not be exposed to vapors which condense and build up to high thickness	Clean-room type environment preferred, 100000 class
EXTERNAL INTERFERENCES	Magnetic Fields	$<2\times10^{4}$ tesla at detector unit	TBD
	RF fields	$<10^{-TBD}$ V m^{-1}, $<10^{-TBD}$ W m^{-2}	TBD
	Ionizing particles	<0.01 count sec^{-1} in detector unit. Detectors will require power down and special Shielding in high flux conditions such as South Atlantic Anomaly crossings.	Crossings through South Atlantic Anomaly must not generate delayed radioactivity in surrounding equipment and structures. Detector package to be retracted into protective shield box.

Table V. Recorded Data Requirements

CLASS	DESCRIPTION	FORMAT	READ-OUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION(2)
SCIENTIFIC:							
Detector Pulse	Main pulse amplitude, crystal detector code, time differential, code of detector with simultaneous 511 keV pulse	digital 32 bit	60 sec^{-1}	1 920 bps	Continuously after instrument turned on (1)	960 Mbits	5:1
Shield Rates	a. Count rate, all pulses	digital 8 bit	3 sec^{-1}	24 bps	(1)	12 Mbits	20:1
	b. Count rate, veto pulses	digital 8 bit	3 sec^{-1}	24 bps	(1)	12 Mbits	20:1
INSTRUMENT HOUSEKEEPING	100 readout points, commutated sampling	digital 8 bit	1 sec^{-1}	8 bps	(1)	4 Mbits	1:1
CREW'S ANNOTATION	Voice comments Logbook entries	"analog" written	as reqd	BW>1 kHz	(1)	120-144 hours	-
SUPPORT EQUIPMENT:							
Proton Flux Detector	Pulse amplitude + code	digital 12 bit	10 sec^{-1}	120 bps	(1)	60 Mbits	1:1
SUBSYSTEMS:							
Spacecraft Attitude Angles	IMU signals	dig. 3x15 bit	0.01 sec^{-1}	0.45 bps	(1)		
Gimbal Angles	Angular encoders	dig. 2x15 bit	0.05 sec^{-1}	1.5 bps	(1)	16 Mbits	1:1
Rate Gyros	Angular rates	dig. 2x10 bit	0.5 sec^{-1}	10 bps	(1)		
Timing	Clock reference	digital 20 bit	1 sec^{-1}	20 bps	(1)		

NOTES: (1) Equipment is operating and data is recorded at all times between turn-on and shutdown. Recording continues even if not observing a specific source.

(2) Only data buffering is considered, using simple storage, processing and coding techniques. Further compression can be achieved with standard compression algorithms.

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achieve the specified scientific objectives of the instrument.

In addition to the recording of this data, a major portion of it must be available for real-time monitoring at the controls and displays console, as defined in 2.8 below.

The possibility of in-flight support by ground-based scientific personnel must be included. Ground support of this type will interface with the observation crew, through the voice link. It is anticipated that all commands to the scientific and support equipment will be performed by the observation crew, through the controls and displays console.

Reference timing signals must be available with the scientific and support data. It must be possible to correlate this data with GMT to within an absolute accuracy of less than 1 msec.

2.7 Pointing - The instrument requires that the axis of the detector field of view be pointed to the source of interest within ± 0.02 rad (± 1.2 degrees) about two axes orthogonal to the field of view axis. Once the specified orientation accuracy is achieved, it is necessary that it be maintained with a stability of ± 0.003 rad (± 10 arc minutes) maximum angular drift. There are no angular rate tolerances.

To achieve these tolerances, in view of the critical orientation constraints on the shuttle vehicle, it is necessary to mount the detector units on a gimbal system which can provide roughly hemispherical orientation freedom for the field of view axis. Besides providing a method to decouple the instrument from the vehicle, the gimbals must be capable of reorienting the instrument from one source to another with slewing rates of at least 0.1 rad sec^{-1} (6 degrees per second) about both gimbal axes. This re-orientation of the instrument is expected to be performed at least twice per orbit.

2.8 Controls and Displays - The functional requirements for the controls and displays required to operate the instrument are listed in tables VI and VII. Table VI lists the requirements for the scientific equipment, and table VII lists the requirements for the support equipment.

2.9 Preflight/Postflight Ground Support - The ground support requirements are detailed. These include equipment and facilities, and a brief discussion of the major functions required after instrument installation.

Table VI. Scientific Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
Main Power	ON/OFF	ON/OFF
PMT HV PS	ON/OFF	ON/OFF (7)
PHA Gain Adj	Analog (4)	Digital (4)
Calibrate	1-4	1-4
γ-Ray Spectrum (PHA)	ON/OFF	Analog
Experiment Status	START/STOP	READY/OPERATE

Table VII. Support Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
<u>Gimbal System:</u>		
Main Power	ON/OFF	ON/OFF
Primary Instrumentation	ON/OFF	ON/OFF
Shuttle Celestial Orientation	-----	Digital (RA+δ)
Gimbal Angles	+/- (2)	Digital
Field Of View Orientation	-----	Digital (RA+δ)
Source Map	ON/OFF	CRT(?)
Caging Control	ON/OFF	ON/OFF
Deployment System		
Main Power	ON/OFF	ON/OFF
Drive Motor	DEPLOY/RETRACT	DEPLOYED/UNLOCKED/LOCKED
Protective Shield Box	OPEN/CLOSE	
Drive	OPEN/CLOSE	
Status		OPEN/CLOSED
Proton Flux Detector		
Main Power	ON/OFF	ON/OFF
Count Rate	-----	Digital
Alert	Analog (Threshold)	RETRACT

2.9.1 Ground Support Equipment and Facilities - The major facility and equipment requirements are listed in table VIII.

2.9.2 Test, Checkout and Calibration - After instrument installation is completed according to established interface requirements, test and checkout of the complete experiment system as an integral package is required. The precedure for these operations is not defined. Some of the operations that will definitely be required can be identified:

a. Signal test of each Ge(Li) crystal with true photon flux into the detectors, monitored at the data recording point.

b. Operational verification of the gimbal/detector module system for slewing rates, accuracies of pointing.

c. Operational verification of the protective shield system and deployment mechanism, and of the frost-buildup prevention device.

A final calibration of the detector characteristics is required prior to launch, and repeated after the instrumentation returns from orbit and before it is dismantled.

2.9.3 Accessibility Requirements - After prelaunch checkout and calibration, access is required to the scientific equipment for maintenance of the cryogenic refrigeration system, which must be maintained in operational status on a continuous basis. Also, should the detector unit be subjected to environments outside those specified in table IV, a verification of instrument health will be required.

2.10 Post-Mission Refurbishment - The scientific equipment should only require refurbishment of the cryogenic refrigerator unit to ready the experiment for reflight. All other units must undergo the normal calibration sequences before reflight.

2.11 Orbital Parameters - For this instrument, it would be advisable to avoid the detrimental effects caused by energetic particles which populate the South Atlantic Anomaly and by the energetic cosmic nuclei.

Polar orbits are particularly undesirable due to the high flux of cosmic nuclei at high geomagnetic latitudes.

The South Atlantic Anomaly's geographic location is such that it can only be avoided by selecting low inclination (nearly

Table VIII. Ground Support Requirements

EQUIPMENT	Controlled Environment Storage Container
	Handling/Installation Fixture
	Cryogen Storage Container
	Cryogen Refill/Replenishment and On-Pad Maintenance System
	Calibrated γ-Ray Sources
	Checkout/Calibration Monitor System
FACILITIES	Clean Room (100 000-class low humidity)
	Prelaunch Environment Control Facility

equatorial) orbits, which are not within the capabilities of the shuttle carrier.

From the standpoint of background particle flux, the preferred orbits are those with low altitudes (<250 km = 135 nautical miles) and with inclinations as low as achievable (probably 0.50 rad = 28.65 degrees).

3. PROGRAMMATICS

The information in this section consists mostly of subjective estimates which are generally not supported, and probably cannot be supported, by any extensive analysis. Personal experiences with simpler instrumentation have been used for extrapolation into vastly different equipment characteristics.

3.1 Equipment Cost and Schedule - NASA has two estimates for the cost of this instrument. One, from the HEAO-B spacecraft development contract is for $7.6 million (1971) with 3 years development time, for installation in an unmanned spacecraft. The other is from the Shuttle Payload Planning Activity, which indicates $14 million (1969) and 4 years development time. NASA estimates are used for extrapolation to the estimates shown in table IX.

3.2 Safety Considerations - As currently designed, all the scientific equipment and the majority of the support equipment (except for the controls and displays console and the data management subsystem's tape recorder) are located outside the crew compartment. There are no pyrotechnic or explosive devices required for this instrumentation. Extravehicular activity is not considered for this program.

The use of a cryogenic refrigerator in the detector package should not present any hazards. While the refrigerator design is not complete, it is simple to develop cryogenic refrigerators in which there exists no critical condition that would jeopardize safety.

3.3 Reliability - Equipment reliability depends primarily on the level of effort devoted to this subject during the design, development, fabrication, and test phases of the equipment.

Probable mean-time-between-failure estimates are given in table X, for the three types of cost estimates associated with table IX.

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)			(1.70)	(1.70)	(2.50)	(1.40)		$ 7.30
PRODUCTION-FIRST ARTICLE				(0.90)	(1.80)	(1.80)		4.50
								$ 11.80

TABLE IX - SCHEDULE AND COST ESTIMATES, GAMMA-RAY SPECTROMETER

Table X. Mean Time Between Failure Estimates

LEVEL / UNITS	LABORATORY UNITS	SPACE HARDENED	SPACE QUALIFIED
Detector Unit	200	1 000	5,000
Electronics Unit	1 000	5 000	10 000
Cryogenic Refrigerator	200	1 000*	2 000*

NOTES: MTBF values are in hours.

*Cryogenic Refrigerator requires replenishment. Shelf life after cryogen installed estimated as 500 hours.

4. NOTES

4.1 Bibliography - This report contains information obtained from the following documents. The documents are not referred to in the text.

a. Reference Earth Orbital Research and Applications Investigations (Blue Book), Volume II, Astronomy. January 15, 1971.

b. A High Resolution Gamma-Ray Spectrometer for the 0.06 to 10 MeV Region, Experiment Proposal for High Energy Astronomy Observatory (HEAO) by Dr. Allan S. Jacobson et al., Jet Propulsion Laboratory, California Institute of Technology, Pasadena California, May 18, 1970.

4.2 Abbreviations

ASMDS	Astronomy Sortie Missions Definition Study
avg	average
bps	bits per second
cm	centimeters
CsI(Na)	sodium-doped cesium iodide scintillator
CRT	cathode ray tube
FWHM	full-width, half-maximum
Ge(Li)	lithium-drifted germanium semiconductor
GMT	Greenwich Mean Time
HEAO	High Energy Astronomy Observatory
HV	High Voltage
IMU	Inertial Measurement Unit
K	degrees Kelvin
keV	kiloelectron volt
kg	kilogram
M	mega
m	meter
MeV	megaelectron volt
msec	millisecond
MTBF	mean-time-between-failure
N	Newton
PHA	Pulse Height Analyzer
pk	peak
RA	Right Ascension
rad	radian
RF	radio frequency
sec	second

S.P.P.A.	Shuttle Payload Planning Activity
sr	steradian
TBD	To Be Determined
V	volt
W	watt
δ	declination angle

2.13 LOW BACKGROUND GAMMA-RAY DETECTOR

ASM-EXP-204-8
May 3, 1972

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

Baseline Experiment Definition Document (BEDD): Low Background Gamma-Ray Detector

Contract GC1-115076

Prepared by:

J. Dawson

Approved by:

H. O. Ankenbruck
Project Manager

The Bendix Corporation
Navigation & Control Division
Denver Facility
Denver, Colorado

CONTENTS

CONTENTS (Concluded)

1. INTRODUCTION

The purpose of this document is to define a baseline Low Background Gamma-Ray Detector instrument for the ASMDS.

The scientific objectives, configurations, operational requirements, environmental requirements, data, pointing, and controls and displays requirements, estimated ground support equipment and post-mission refurbishment requirements are identified.

2. DISCUSSION

2.1 Scientific Objectives - The scientific objective of the Low Background Gamma-Ray Detector is to investigate the photon spectrum from point, diffuse, and line sources over the energy range from 0.3 to 10 MeV (0.048 to 1.6 aJ). The photon sensitivity and background signal rejection characteristics of the γ-Ray Detector are designed to provide excellent scientific data return from observing missions of comparatively short duration, such as the Astronomy Sortie missions.

2.2 Instrument Description - The instrument consists of four identical detector modules, mounted in a gimbal system by means of a mounting frame, plus an electronics package which should be located near the detector modules, but not necessarily on the gimbal system.

A schematic view of a detector module is shown in figure 1. Seven separate scintillation crystal detectors are included in each module. The collimation shield for the six exterior scintillators restricts the sensitivity to a conical region of 0.5 rad (28 degrees) full-width half maximum (FWHM) angle. The central scintillator views a larger region, with 0.95 rad (55 degrees) FWHM angular sensitivity. The "narrow" field of the exterior detectors is designed for observation of discrete or point sources, while the "wide" field of the central detector is optimized for the measurement of the diffuse component, in the presence of the background resulting from energetic cosmic nuclei.

The collimating (active anticoincidence) shield also surrounds the main scintillation crystal detectors, to provide an active guard system that recognizes when the path of the detected event is outside the nominal acceptance window.

Each one of the main scintillation crystals is viewed by an individual photomultiplier tube (PMT). Each half of the guard shield is viewed by six PMTs. A plastic scintillator shield covers

the front apertures, to recognize and separate charged particle events from photon events. This anticoincidence shield is coupled to six PMTs.

The main photon-sensing scintillators are of the "phoswich" type. Each scintillator consists of a thallium-doped sodium iodide (NaI(Tl)) crystal, optically coupled through a thallium-doped cesium iodide (CsI(Tl)) crystal to a PMT. Risetime discriminators permit separating the 0.25 μsec fluorescent decay constant for events in the NaI(Tl) crystal from the 1.1 μsec events in the CsI (Tl) crystal. An anticoincidence is generated if a substantial component of "slow light" is present, thus providing shielding of the detectors on the side opposite the aperture, without including the inert mass of the photomultiplier tubes within the anticoincidence shield.

Each detector has its own high voltage supply, preamplifier, and 512-channel pulse-height-analyzer (PHA). Separate high voltage supplies, amplifiers, and discriminators are used with each shield piece.

2.3 Instrument Interfaces and Characteristics - Descriptions of experiment and support equipment characteristics and mounting arrangements follow. The requirements shown are tentative, subject to extensive modifications if integration trade studies show that the scientific objectives can be achieved with simplier equipment and requirements.

2.3.1 Interface Block Diagram - The equipment interface diagram is shown in figure 2. This diagram identifies the major interfaces between the instrument and the spacecraft subsystems.

The Wide Coverage X-Ray Detector is tentatively shown in figure 2 (and in table II) as a support unit. It is not essential for this unit to be included. Should it be possible to include this detector within the payload constraints, the transient high energy events which cosmological theories predict could be examined over this critical energy range.

2.3.2 Scientific Equipment Characteristics - Preliminary scientific equipment characteristics are listed in table I.

2.3.3 Support Equipment Characteristics - Preliminary estimates of the characteristics of the support equipment required for this instrument are listed in table II.

2.3.4 Instrument Mounting and Alignment Requirements - The proposed mounting arrangement for the four detector modules is shown in sketch form in figure 3.

2.4 Operations - The participation of the crew in the functions associated with this instrument is detailed.

2.4.1 Functional Flow Diagram - A gross outline of the functions required is shown in figure 4.

2.4.2 Instrument Preparation Requirements - After the Shuttle has achieved stable orbit, and before any functions are performed with the instrument, a safety check of the instrument and support equipment is required. Since all the equipment except the control console is outside the pressurized cabin, the safety check is performed visually through a viewing window.

Electrical power is turned onto the equipment from the control console.

The launch restraints are released, and the gimbals supporting the instrument are elevated, if this deployment technique is used. The crew then performs a functional check on the experiment system (instrument and support equipment) to verify that the specified operations can be performed.

A calibration sequence follows. The calibration operation will be limited to artificial stimuli of the electronic systems. The calibration sequence can be performed automatically or by manual control. For automatic calibration, a stored computer program is required. Energy calibration of the main detector crystals will occur automatically as a result of the γ-ray lines from the earth's albedo, specifically the 511 keV line from positron annihilation, and the 2.2 MeV line from deuteron formation will provide data for scaling the sensitivity of the scintillator crystal and photomultiplier tube combinations.

2.4.3 Instrument Operation Requirements - The instrument has only one mode of operation during scientific data acquisition, namely, all detector modules viewing a specific celestial region.

Observation periods with this instrument are necessarily long, due to the low expected flux of γ-rays from both discrete and diffuse sources, and also due to the high interfering background due to interactions of energetic cosmic nuclei with spacecraft materials. It should be expected that any region of specific

interest will be observed during several successive orbits, to accumulate observation times of the order of 10^4 seconds (slightly less than three hours).

In the interest of acquiring the maximum scientific data possible within the mission duration constraints, the observation program must be carefully planned. The orientation of the experiment should be changed to view another source of interest whenever the source currently under observation becomes subject to interference from the albedo. The ideal situation would be where any source not occulted by the earth could be viewed by the instrument; in this case, the instrument could always be slewed to view another source of interest whenever the earth or its atmosphere interferes with the current source. Further details of this requirement are deferred to the discussion on instrument pointing.

Crew involvement in the operation of the instrument is high during the source acquisition phases. The selection of a new source to observe, based on vehicle orientation, viewing constraints, and scientific priority of the sources, could be performed with support from a ground station, or by an on-board computer system. Slewing of the instrument to the selected region is performed manually. Once oriented to the source, the automatic tracking system takes over, and the crew's involvement reduces to occasional monitoring for unusual conditions in the instrument and in the background flux, until the observation is complete or until the source approaches the earth's terminator.

One aspect of source observation which has not been extensively investigated is the requirement to orient the field of view over a range of celestial orientations in the vicinity of a point source of interest, to obtain improved positional accuracies. This capability could be obtained by introducing offsets in the commanded instrument orientation on successive viewing periods. Another approach would be to offset the viewing axes of the four modules, i.e., mount the four modules shown in figure 3 with intentional tilt of (say) 7 degrees toward the center.

2.4.4 <u>Instrument Post-Operation Requirements</u> - The major post-operation functions are basically the reverse of the deployment functions:

a. Place the instrument in the launch orientation.

b. Retract the gimbals (if extension is used).

c. Reset the launch restraints.

d. Turn off electrical power, prepare the instrument for reentry.

These operations are all performed by the crew through the controls and displays console.

2.4.5 Typical Instrument Operation Timelines - The experiment operational characteristics described in the above paragraphs are summarized in table III.

2.5 Environment - The environmental requirements and constraints associated with this instrument are listed in table IV. The electromagnetic interference susceptibility of the detector modules is primarily determined by the characteristics of the shielding and isolation that is included in the detector designs. These units have not progressed beyond the conceptual design phase, thus no numerical threshold values can be specified.

Count rate limiters and signals from the proton flux detector will automatically disable the detectors during crossings of the South Atlantic Anomaly; the detectors will return to normal operation when the particle flux drops below a preset threshold.

2.6 Data - The primary scientific data is described in table V, together with the auxiliary data required. This complete data package represents the basic information which will be used to achieve the specified scientific objectives of the instrument.

In addition to the recording of this data, it must be available for real-time monitoring at the Controls and Displays Console, as defined in 2.8.

The possibility of in-flight support by ground-based scientific personnel must be included. Ground support of this type will interface with the observation crew, through the voice link. It is anticipated that all commands to the scientific and support equipment will be performed by the observation crew, through the controls and displays console.

Reference timing signals must be available with the scientific and support data. It must be possible to correlate this data with GMT to within an absolute accuracy of less than 1 msec.

2.7 Pointing - The instrument requires that the axis of the field of view of the four detector modules be pointed to the source of interest within ± 0.02 rad (± 1.2 degrees) about two axes orthogonal to the field of view axis. Once the specified orientation

accuracy is achieved, it is necessary that it be maintained with a stability of ±0.003 rad (±10 arc minutes) maximum angular drift. There are no angular rate tolerances.

To achieve these tolerances, in view of the critical orientation constraints on the shuttle vehicle, it is necessary to mount the detector units on a gimbal system which can provide roughly hemispherical orientation freedom for the field of view axis. Besides providing a method to decouple the instrument from the vehicle, the gimbals must be capable of reorienting the instrument from one source to another with slewing rates of at least 0.1 rad sec^{-1} (6 degrees per second) about both gimbal axes. This re-orientation of the instrument is expected to be performed at least twice per orbit.

As is characteristic of all detectors with limited angular resolution, intentional offset pointing of co-aligned detectors during extended observation periods will enhance the value of the acquired data by providing improved information on the location of discrete sources and of their γ-ray flux.

2.8 Controls and Displays - The functional requirements for the controls and displays required to operate the instrument are listed in tables VI and VII. Table VI lists the console requirements for the scientific equipment, and table VII lists the console requirements for the support equipment.

2.9 Preflight/Postflight Ground Support - The ground support requirements are detailed. These include equipment and facilities, and a brief discussion of the major functions required after instrument installation.

2.9.1 Ground Support Equipment and Facilities - The major facility and equipment requirements are listed in table VIII.

2.9.2 Test, Checkout and Calibration - After instrument installation is completed according to established interface requirements, test and checkout of the complete experiment system as an integral package is required. The procedure for these operations is not defined. Some of the operations that will definitely be required can be identified:

a. Signal test of each phoswich system with true photon flux into the detectors, monitored at the data recording point.

b. Operational verification of the gimbal/detector module system for slewing rates, accuracies of pointing.

A final calibration of the detector characteristics is required prior to launch, and repeated after the instrumentation returns from orbit and before it is dismantled.

2.9.3 Accessibility Requirements - After prelaunch checkout and calibration, access is not required to the scientific equipment. Should the instrument be subjected to environments outside those specified in table IV, a verification of instrument health will be required.

2.10 Post-Mission Refurbishment - The scientific equipment should only require normal calibration operations before reflight.

2.11 Orbital Parameters - For this instrument, it would be advisable to avoide the detrimentral effects caused by energetic particles which populate the South Atlantic Anomaly and by the energetic cosmic nuclei.

Polar orbits are particularly undesirable due to the high flux of cosmic nuclei at high geomagnetic latitudes.

The South Atlantic Anomaly's geographic location is such that it can only be avoided by selecting low inclination (nearly equatorial) orbits, which are not within the capabilities of the shuttle carrier.

From the standpoint of background particle flux, the preferred orbits are those with low altitudes (<250 km = 135 nautical miles) and with inclinations as low as achievable (probably 0.50 rad = 28.65 degrees).

3. PROGRAMMATICS

The information in this section consists mostly of subjective estimates which are generally not supported, and probably cannot be supported, by any extensive analysis. Personal experiences with simpler instrumentation have been used for extrapolation into vastly different equipment characteristics.

3.1 Equipment Cost and Schedule - NASA has two estimates for one module of this instrument. One, from the HEAO-B spacecraft development contract is for $6.5 million (1971) with 3 years development time, for installation in an unmanned spacecraft. The other is from the Shuttle Payload Planning Activity, which indicates $15 million (1969) and 3 years development time. NASA

estimates are used for extrapolation to the estimates shown in table IX.

3.2 Safety Considerations - As currently designed, all the scientific equipment and the majority of the support equipment (except for the controls and displays console and the data management subsystem's tape recorder) are located outside the crew compartment. There are no pyrotechnic or explosive devices required for this instrumentation. Extravehicular activity is not considered for this program.

3.3 Reliability - Equipment reliability depends primarily on the level of effort devoted to this subject during the design, development, fabrication, and test phases of the equipment.

Probable mean-time-between-failure estimates are given in table X, for the three types of cost estimates associated with table IX.

4. NOTES

4.1 Bibliography - This report contains information obtained from the following documents. The documents are not referred to in the text.

a. Reference Earth Orbital Research and Applications Investigations (Blue Book), Volume II, Astronomy. January 15, 1971.

b. A Sky Survey Experiment for 0.3-10 MeV for γ-Ray Sources for HEAO-A, by Dr. Laurence E. Peterson, Principal Investigator, University of California, San Diego, California, May 1970.

4.2 Abbreviations

ASMDS	Astronomy Sortie Missions Definition Study
avg	average
bps	bits per second
cm	centimeters
CsI(Na)	sodium-doped cesium iodide scintillator
CRT	cathode ray tube
FWHM	full-width, half-maximum
GMT	Greenwich Mean Time
HEAO	High Energy Astronomy Observatory
HV	High Voltage

IMU	Inertial Measurement Unit
K	degrees Kelvin
keV	kiloelectron volt
kg	kilogram
M	mega
m	meter
MeV	megaelectron volt
msec	millisecond
MTBF	mean-time-between-failure
N	Newton
NaI(Tl)	thallium-doped sodium iodide scintillator
PHA	Pulse Height Analyzer
PMT	photomultiplier tube
pk	peak
RA	Right Ascension
rad	radian
RF	radio frequency
sec	second
S.P.P.A.	Shuttle Payload Planning Activity
sr	steradian
TBD	To Be Determined
V	volt
W	watt
δ	declination angle

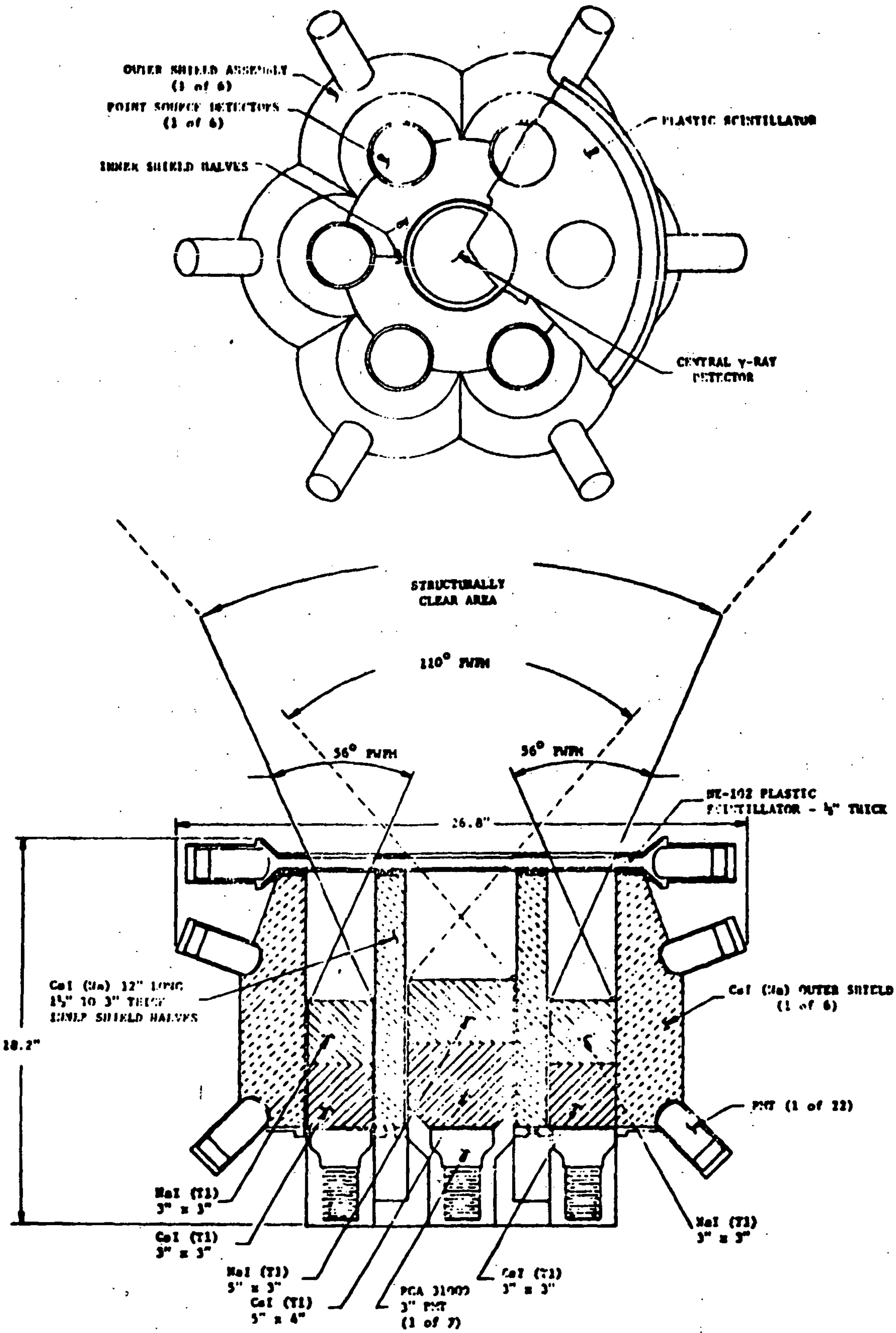


Figure 1. Dimensional Sketch of Single Detector Module

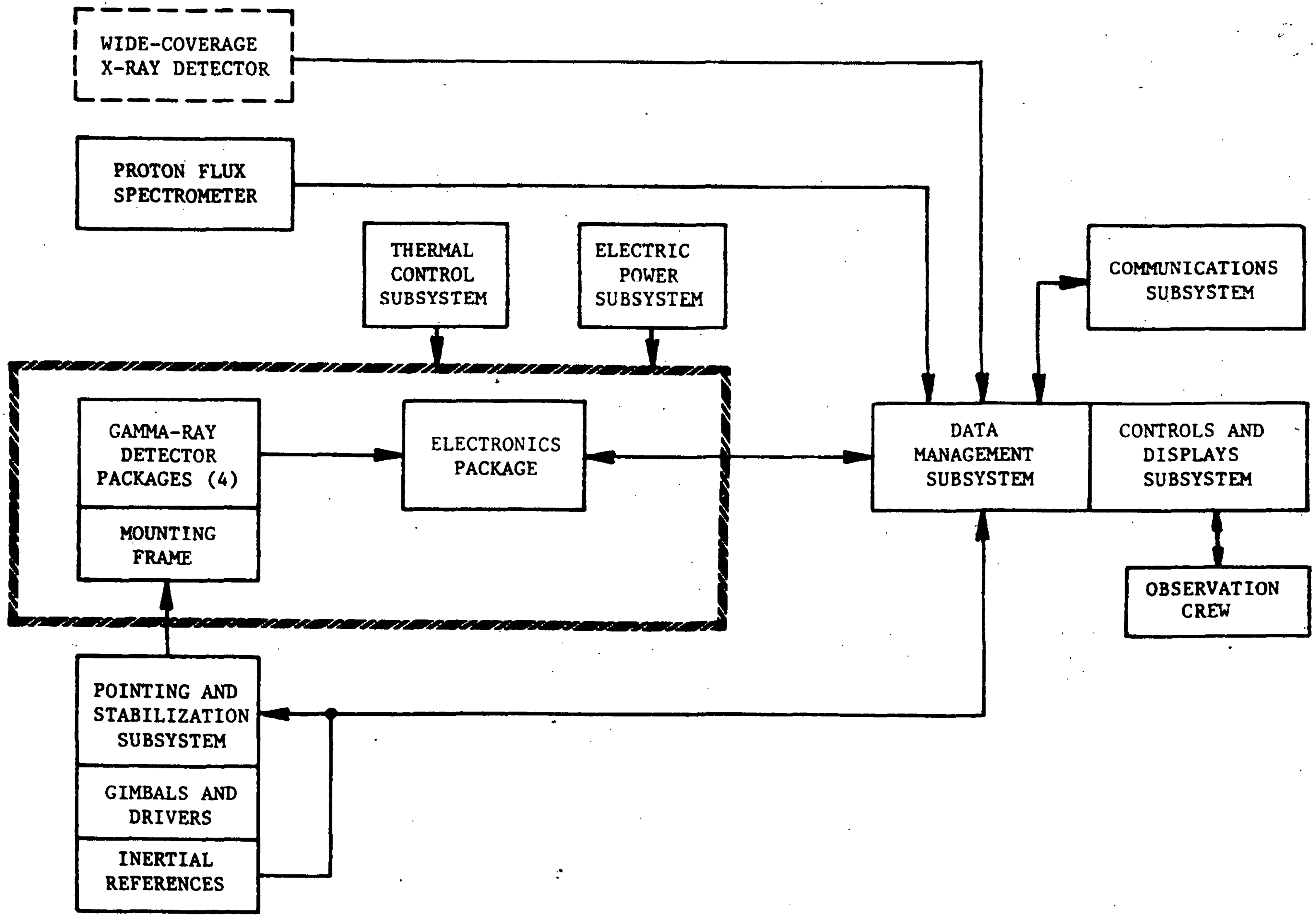
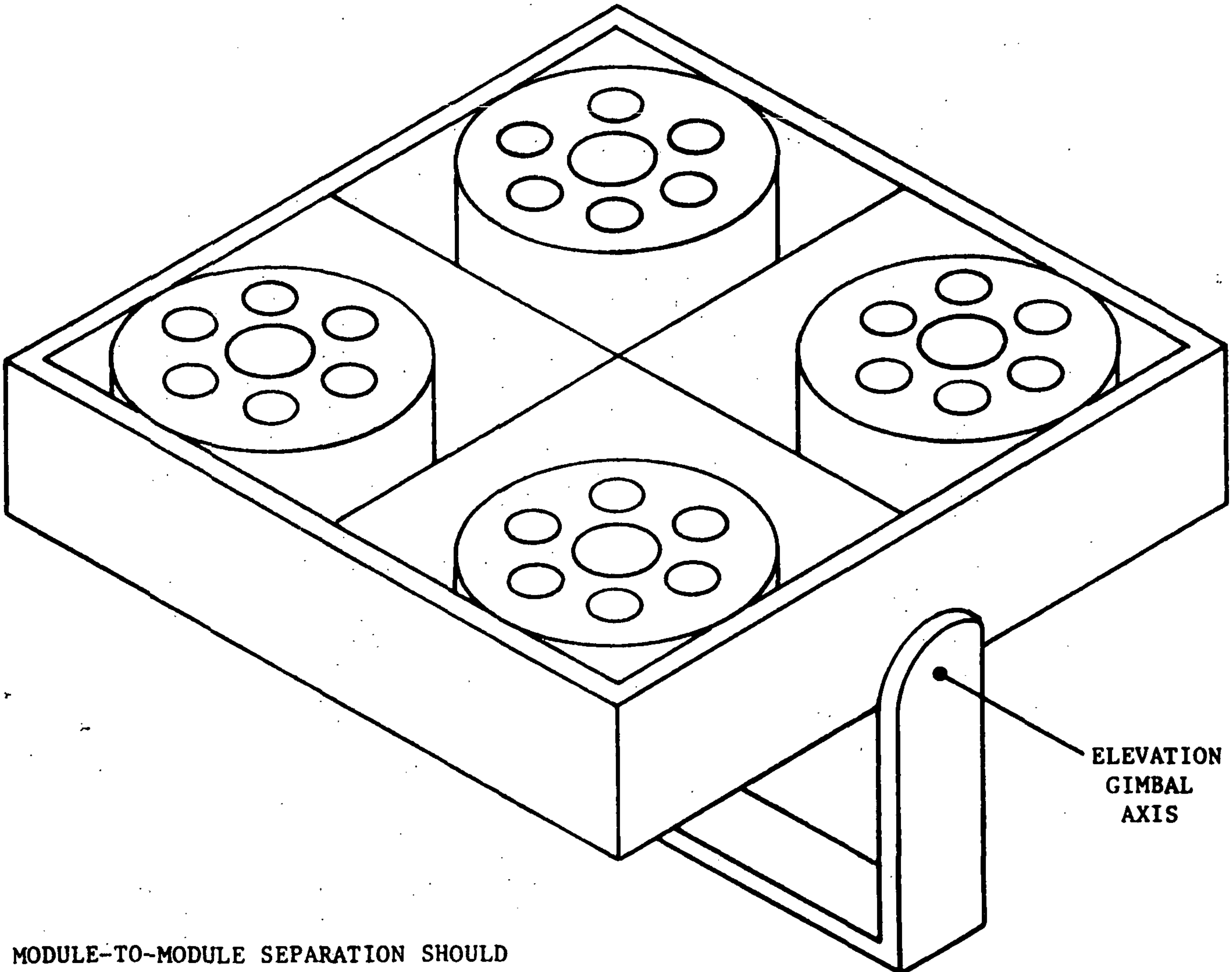


Figure 2. Interface Block Diagram, Low Background Gamma-Ray Detector



MODULE-TO-MODULE SEPARATION SHOULD BE MAXIMUM POSSIBLE WITHIN THE SPECIFIED ENVELOPE DIMENSIONS.

MODULE TO MODULE ALIGNMENT WITHIN 0.005 RAD.

GIMBAL AXES TO SPACECRAFT AXES ALIGNMENT WITHIN 0.009 RAD.

Figure 3. Suggested Mounting Arrangement

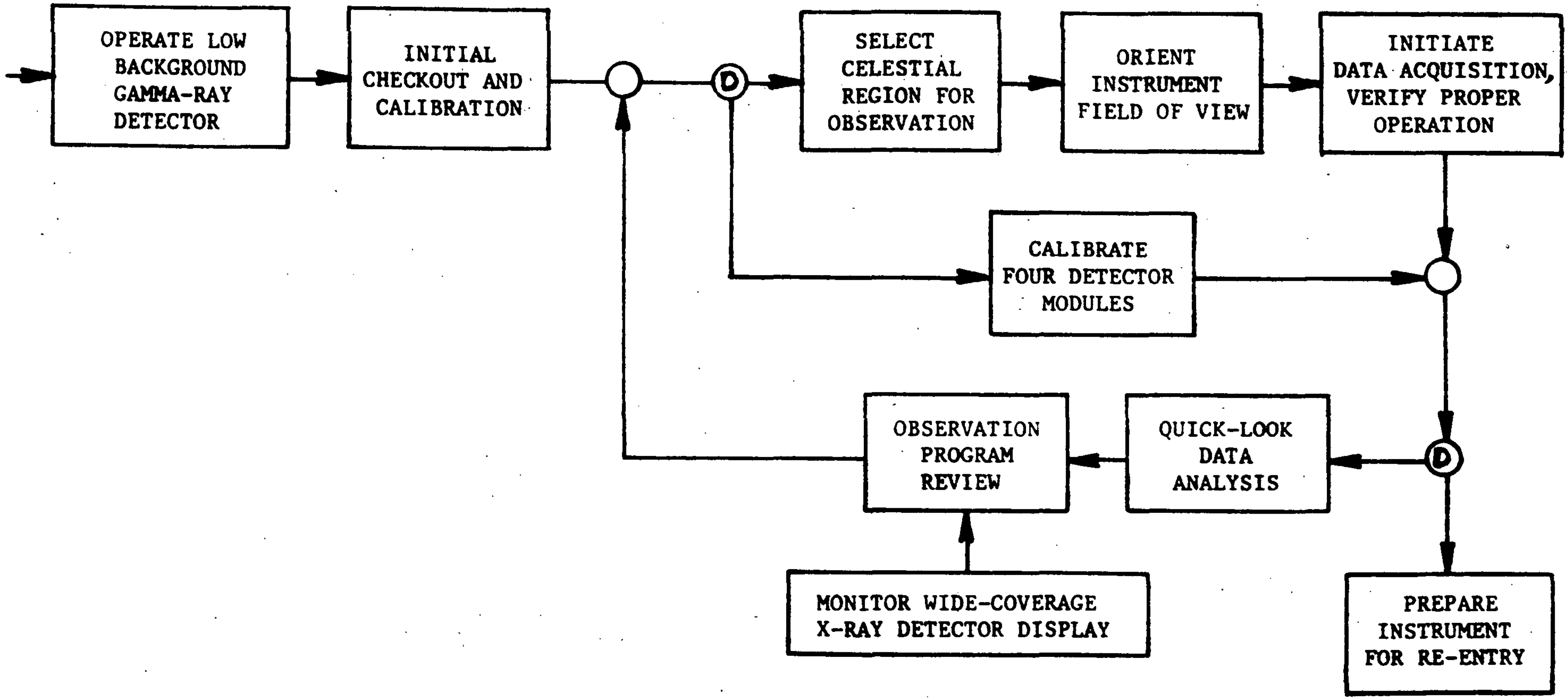


Figure 4. Functional Diagram, Low Background Gamma Ray Detector

Table I. Scientific Equipment Characteristics

DESCRIPTION	QTY	DIMENSIONS				VOLUME m3	WEIGHT kg	POWER watts
		WIDTH cm	HEIGHT cm	LENGTH cm	DIAMETER cm			
DETECTOR MODULES	4			47	68	0.12 each 0.48 total	226 each (500 lb) 904 total (2,000 lb)	11 pk 10 avg 44(total) pk
ELECTRONICS PACKAGE	1	30	30	30		0.03	10 (22 lb)	20 avg 67 pk
MOUNTING FRAME	1	140	50	140		0.98 (detector modules included within this volume)	80 (176 lb)	

Table II. Support Equipment Characteristics

DESCRIPTION	QTY	DIMENTIONS				VOLUME m3	WEIGHT kg	POWER watts
		WIDTH cm	HEIGHT cm	LENGTH cm	DIAMETER cm			
PROTON FLUX DETECTOR	1			40	20	0 012	10	30
GIMBALS AND DEPLOYMENT MECHANISM	1	TBD						TBD
CONTROLS AND DISPLAYS CONSOLE	1	TBD						TBD
Wide COVERAGE X-RAY CONSOLE (this instrument is suggested as a support unit for the Gamma Ray Detector, but is not specified as a requirement.)	1		120		200	4.0	250	50-200

Table III. Typical Operational Timeline

SUPPORT REQUIREMENTS \ OPERATION SEQUENCE	INITIAL						REPEATED (DATA ACQUISITION CYCLE)						FINAL				
	SAFETY CHECK	ELECTRICAL POWER ON	RELEASE LAUNCH RESTRAINTS	FUNCTIONAL CHECKS	ELECTRONIC CALIBRATION	ESTABLISH ORIENTATION REFERENCES	SELECT SOURCE OF INTEREST	ORIENT DETECTOR FIELD OF VIEW	INITIATE DATA ACQUISITION AND VERIFY EQUIPMENT OPERATION	SCIENTIFIC DATA ACQUISITION	QUICK-LOOK DATA ANALYSIS	SELECT SOURCE OF INTEREST (START OF NEW OBSERVATION CYCLE)	POWER DOWN DETECTOR HIGH VOLTAGES	SET GIMBALS TO LAUNCH POSITION	RESET LAUNCH RESTRAINTS	TURN OFF ELECTRICAL POWER	PREPARE FOR REENTRY
TIME (MINUTES)	2-20	2	2	10	10	5	1	1	1	45-450	5	1	1	1	2	1	
CREW PARTICIPATION (ASTRONAUT/ASTRONOMER)	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
GAMMA-RAY MODULES	-	X	*	X	*	*	*	X	X	X	*	*	*	*	*	-	-
ELECTRONICS PACKAGE	-	X	*	X	X	*	*	X	X	X	X	*	*	*	*	-	-
MOUNTING FRAME	X	-	X	X	-	X	X	X	X	X	-	X	-	X	X	-	-
GIMBALS/POINTING AND STABILIZATION SUBSYSTEM	X	X	X	X	*	X	X	X	X	X	*	X	*	X	X	-	-
PROTON FLUX DETECTOR	X	*	*	X	X	*	*	*	*	*	*	*	*	*	*	-	-
WIDE-COVERAGE X-RAY DETECTOR (OPTIONAL SUPPORT EQUIPMENT)	X	*	-	X	X	*	*	*	*	*	X	*	*	*	*	-	-
CONTROLS AND DISPLAYS CONSOLE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
POWER REQUIREMENTS — SCIENTIFIC EQUIPMENT:	-	70	70	70	111	70	70	70	70	70	70	70	70	70	70	0	-
POWER REQUIREMENTS — SUPPORT EQUIPMENT:	100	300	350	450	300	300	300	400	300	300	300	300	300	400	350	0	-
GIMBAL REQUIREMENTS — SLEWING:			X	X			X					X		X	X		
GIMBAL REQUIREMENTS — SOURCE TRACKING:				X		X		X	X	X							

NOTE: * ASTERISK INDICATES EQUIPMENT NOT SPECIFICALLY REQUIRED FOR THE OPERATION, BUT WHICH REMAINS TURNED ON AND DRAWING POWER.

Table IV. Environmental Requirements/Constraints

		OPERATING	NONOPERATING
MECHANICAL	Acceleration	$2\ m\ sec^{-2}$	With launch restraints set, withstands peak values defined for normal launch and reentry.
	Vibration	TBD	
	Acoustic	TBD	
THERMAL	Absolute temperature limits	291 to 297 K	253 to 303 K
	Differential temperature limits	$\Delta T<2$ K across any module	$\Delta T<2$ K across any module
ATMOSPHERE	Pressure	$10^{-1}\ N\ m^{-2}$	$1.2x10^{5}\ N\ m^{-2}$
	Humidity		<2% preferred
	Contaminants	Not highly sensitive to spacecraft effluents	Clean-room type environment preferred, 100000 class
EXTERNAL INTERFERENCES	Magnetic Fields	$2x10^{4}$ tesla at detector unit	TBD
	RF fields	$10^{-TBD}\ V\ m^{-1}$ $10^{-TBD}\ W\ m^{-2}$	TBD
	Ionizing particles	$0.01\ count\ sec^{-1}$ in detector unit. Detectors will require power down in high flux conditions such as South Atlantic Anomaly crossings.	Crossings through South Atlantic Anomaly must not generate delayed radioactivity in surrounding equipment and structures.

Table V. Recorded Data Requirements

LOW BACKGROUND GAMMA-RAY DETECTOR

CLASS	DESCRIPTION	FORMAT	READ-OUT RATE	NOMINAL DATA RATE	DUTY CYCLE	TOTAL DATA 7-DAY MISSION	POSSIBLE COMPRESSION (2)
SCIENTIFIC							
Detector Signal Pulse	pulse amplitude, detector code, time differential, adjacent shield piece with simultaneous 511 keV pulse	digital 32 bit	100 sec^{-1}	3 200 bps	Continuously after instrument turned on (1)	1 600 Mbits	5:1
Count Rates in Shield Pieces	rate of detected pulses in each of 32 shield pieces	commutated sampling, digital 8 bits	4 sec^{-1}	32 bps	(1)	16 Mbits	20:1
Collimation Veto Pulses	rate of pulses detected in shield pieces used for collimation anticoincidence	commutated sampling, digital 4 bits	4 sec^{-1}	16 bps	(1)	8 Mbits	20:1
INSTRUMENT HOUSEKEEPING	100 readout points, commutated sampling	digital 8 bit	1 sec^{-1}	8 bps	(1)	4 Mbits	1:1
CREW's ANNOTATION	Voice comments Logbook entries	"analog" written	as reqd	BW 1 kHz	(1)	120-144 hours	
SUPPORT EQUIPMENT:							
Proton Flux Detector	Pulse amplitude + code	digital 12 bit	10 sec^{-1}	120 bps	(1)	60 Mbits	1:1
Wide Coverage X-Ray Detector (Optional)	Signal pulses + code: detector,* time differential	digital 20 bit	32 sec^{-1}	640 bps	(1)	320 Mbits	20:1 (3)
SUBSYSTEMS:							
Spacecraft Attitude Angels	IMU signals	dig. 3x15 bit	0.01sec^{-1}	0.45 bps	(1)	16 Mbits	1:1
Gimbal Angles	Angular encoders	dig. 2x15 bit	0.05sec^{-1}	1.5 bps	(1)		
Rate Gyros	Angular rates	dig. 2x10 bit	0.5 sec^{-1}	10 bps	(1)		
Timing	Clock reference	digital 20 bit	1 sec^{-1}	20 bps	(1)		

NOTES:

(1) Equipment is operating and data is recorded at all times between turn-on and shutdown. Recording continues even if not observing a specific source.

(2) Only data buffering is considered, using simple storage, processing and coding techniques. Further compression can be achieved with standard compression algorithms.

(3) Limiting monitor function to large transient X-ray events with preset thresholds yields ratios of 1000:1.

Table VI. Scientific Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
Main Power	ON/OFF	ON/OFF
PMT HV PS	ON/OFF	ON/OFF (7)
PHA Gain Adj	Analog (4)	Digital (4)
Calibrate	1-4	1-4
γ-Ray Spectrum (PHA)	ON/OFF	Analog
Experiment Status	START/STOP	READY/OPERATE

Table VII. Support Equipment Console Requirements

FUNCTION	CONTROL	DISPLAY
GIMBAL SYSTEM		
Main Power	ON/OFF	ON/OFF
Primary Instrumentation	ON/OFF	ON/OFF
Shuttle Celestial Orientation	------	Digital (RA+δ)
Gimbal Angles	+/- (2)	Digital
Field of View Orientation	------	Digital (RA+δ)
Source Map	ON/OFF	CRT(?)
Caging Control	ON/OFF	ON/OFF
PROTON FLUX DETECTOR		
Main Power	ON/OFF	ON/OFF
Count Rate	------	Digital
Alert	Analog (Threshold)	RETRACT
WIDE-COVERAGE X-RAY DETECTOR: (OPTIONAL EQUIPMENT)		
Main Power	ON/OFF	ON/OFF
Primary HV Power Supply	ON/OFF	ON/OFF
Threshold Level Adjust	50 Levels	LEVEL
X-Ray Alert	--	ON/OFF
Experiment Status	START/STOP	READY/OPERATE
Source Coordinates	ON/OFF	(2) DIGITAL
X-Ray Spectrum (PHA)	ON/OFF	ANALOG
Calibration	START/STOP	ON/OFF
Rate Attenuator Select	1-6	1-6
Module HV Power	OFF (154 max)	
Module Integrity		GO/NO-GO

Table VIII. Ground Support Requirements

EQUIPMENT	Controlled Environment Storage Container
	Handling/Installation Fixture
	Calibrated γ-Ray Sources
	Checkout/Calibration Monitor System
FACILITY	Clean Room (100 000-class low humidity)
	Prelaunch Environment Control Facility

YEAR (QUARTER)	-6 1 2 3 4	-5 1 2 3 4	-4 1 2 3 4	-3 1 2 3 4	-2 1 2 3 4	-1 1 2 3 4	0 1 2 3 4	TOTAL COST (MILLIONS)
LAUNCH							▼	
DESIGN, DEVELOPMENT, TEST AND EVALUATION (DDT&E)			(1.80)	(2.40)	(2.30)			$ 6.50
PRODUCTION-FIRST ARTICLE			(0.50)	(2.20)	(2.60)	(2.00)		7.30
								$ 13.80

TABLE IX - SCHEDULE AND COST ESTIMATES, LOW BACKGROUND GAMMA-RAY DETECTOR

Table X. Mean Time Between Failure Estimates

LEVEL UNITS	LABORATORY UNITS	SPACE HARDENED	SPACE QUALIFIED
Detector Units	200	1 000	5,000
Electronics Unit	1 000	5 000	10 000

NOTES: MTBF values are in hours.